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Canadian Aeronautical Journal

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moonlight at noon
Operating in the Arctic areas, aircrew and groundcrew of the Royal Canadian Air Force could throw away the clock and use a calendar— and tear off November, December and January as the period of the long night.
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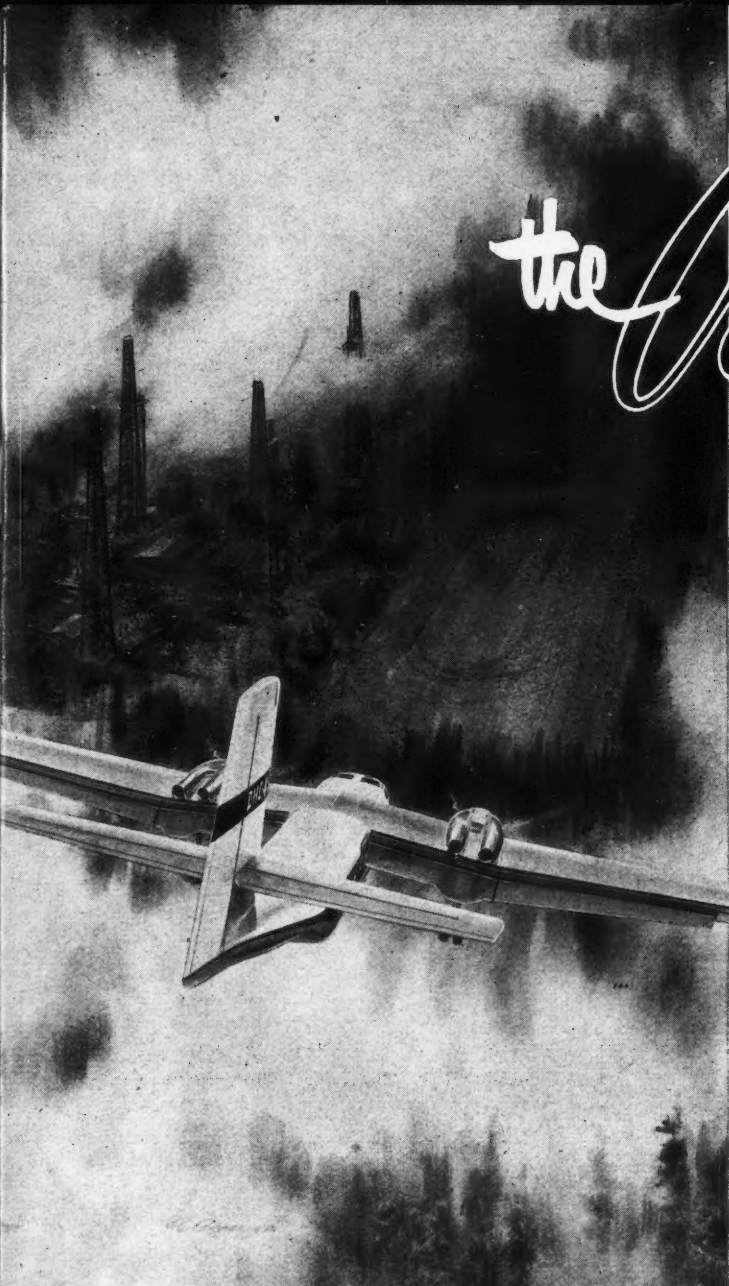

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CANADIAN AERONAUTICAL JOURNAL

FEBRUARY 1959

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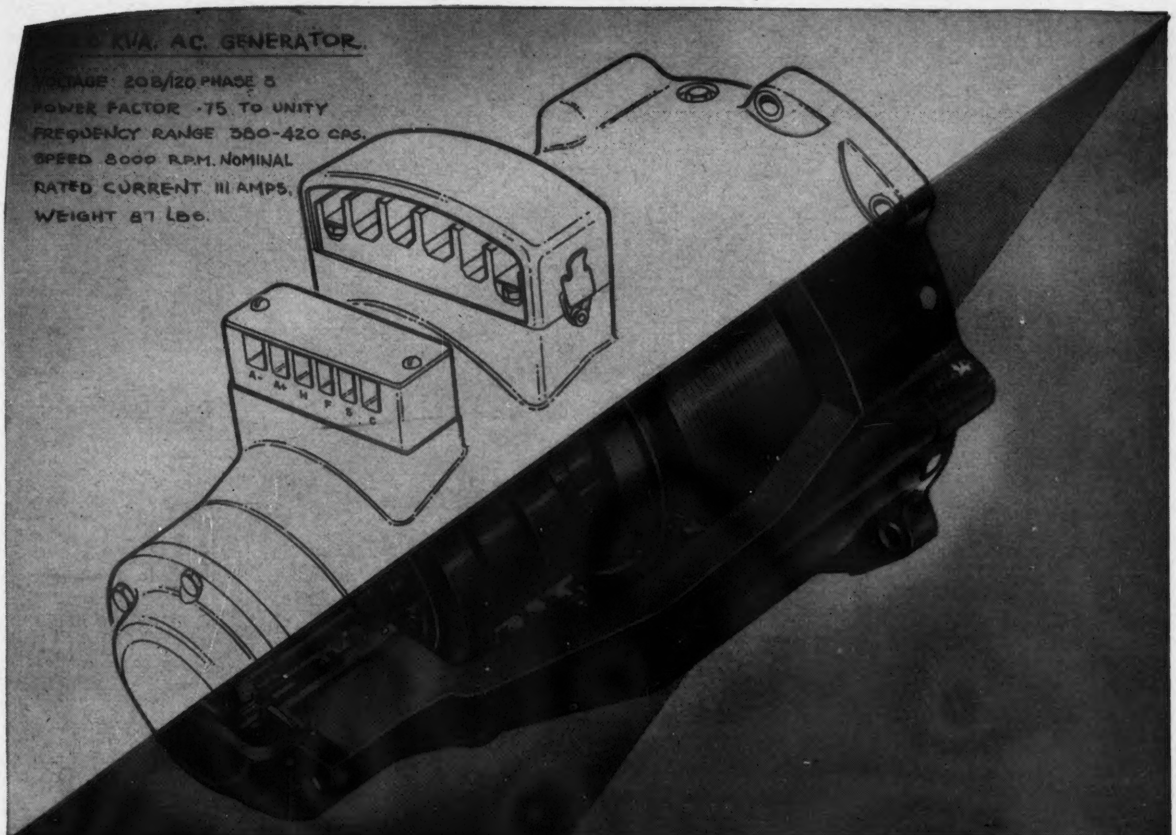

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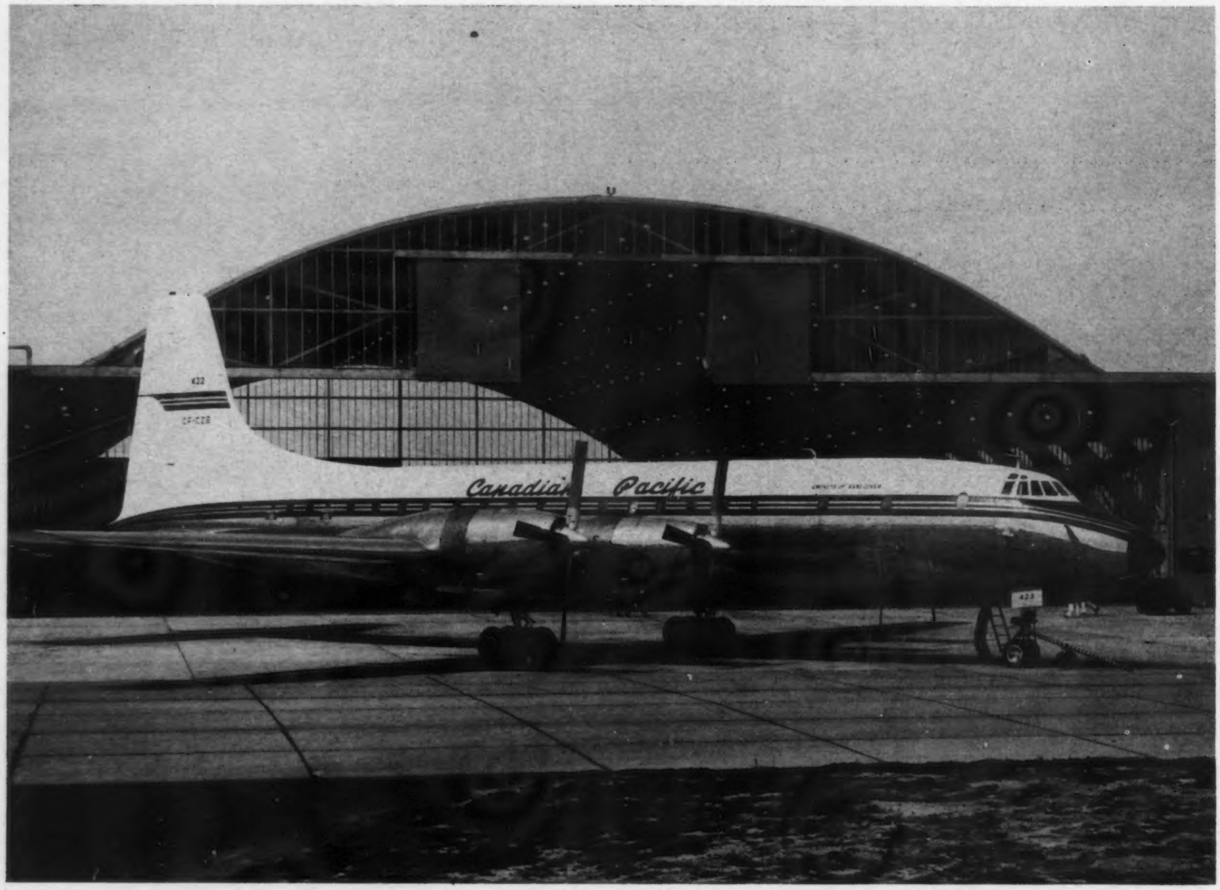
BRITANNIA



Canadian Pacific Air Lines' Britannia (Series 314) powered by four Bristol Proteus 755 turboprop engines.

EDITORIAL

THE FUTURE OF RESEARCH AND DEVELOPMENT

The following is the text of a Memorandum addressed to the Government by the Council of the Institute. It was forwarded to the Prime Minister on the 11th November, 1958.

THE Canadian Aeronautical Institute, which is a professional society of some 2,300 scientists, engineers and technicians engaged in aviation in Canada, has studied the Government statement of the 23rd September on the Canadian Air Defence Programme and is seriously concerned at its implications with regard to the future of research and development of military aircraft and missiles in Canada.

The statement points out that Canadian work in the design, development and production of defence equipment must, in future, be closely integrated with the major programmes of the United States, and continues:

> "The U.S. Government recognizes this, and they now are prepared to work out production sharing arrangements with us."

In so complex a field as aeronautics, in which research, development and production must proceed in an unbroken sequence, any production by other than the originator cannot amount to more than simple manufacture, devoid of any elements of a scientific or engineering nature. If indeed future Canadian contributions are to be confined to production alone, our present resources of scientific and engineering talent in this most exacting field will be wastefully dispersed to other fields and to other countries. It is respectfully submitted that such a result would not be in keeping with the policy of intensification of scientific effort and the pooling of technological resources, agreed upon by the NATO powers after the launching of the first Sputnik.

Moreover we have established in Canada an industry which has contributed to the technological growth of the country and has materially enhanced our scientific stature in the world. To remain technically competitive this industry must be supported by research and development, to foster design and manufacturing activities and to keep abreast of the state of the art. The production capability of the Canadian aviation industry would deteriorate significantly if this element of research and development were allowed to decay; our retention of research and development is essential if the utilization of Canadian facilities is to offer any attraction to the U.S. Government. "Production sharing" alone is not enough; the creative thinking of which we have shown ourselves capable is the most valuable contribution we have to offer.

In drawing attention to these considerations, the Council of the Institute would most respectfully request that the Government should, at an early date, make a clear statement of its policy with regard to future research and development and the steps being taken to conserve our scientific and engineering resources in both men and facilities. We believe that research and development must receive due attention and that vigorous measures must be taken to minimize discontinuities in the process of realignment, which these changes in the Air Defence Programme will inevitably entail. In the present climate of uncertainty, the wealth of technical ability that we now possess can be rapidly dissipated and the progress we have made can be irrevocably lost.

On our part, the Canadian Aeronautical Institute stands ready to assist the Government in every way possible to resolve the formidable problems now confronting the nation.

Celebrating the First Powered Flight in Canada, 23rd February, 1909

SPECIAL ANNIVERSARY MEETING

THE QUEEN ELIZABETH

MONTREAL

23rd and 24th February, 1959

23rd February	Morning	9.00 a.m.	Atmospheric Flight
	Afternoon	2.00 p.m.	Space Flight
		7.00 p.m.	Dinner
24th February	Morning	9.00 a.m.	Propulsion
		12.30 p.m.	Luncheon*
	Afternoon	2.00 p.m.	Satellites

*Sponsored jointly by the Astronautics and Propulsion Sections

ANNUAL GENERAL MEETING

The Annual General Meeting of the Institute
will be held at

KELTIC LODGE
INGONISH BEACH, N.S.

on the

15th, 16th and 17th June, 1959

The Programme, which is now being prepared, will include Sessions on

Flying — Past, Present and Future,
and Hydrodynamics

as well as the annual Business Meetings of the Institute and the Specialist Sections.

This meeting affords an opportunity for the presentation of papers by members of the C.A.I. The Council is most anxious to encourage Canadian papers and hopes that any member wishing to contribute to either of the above-mentioned Sessions will submit a summary of his paper for consideration. Such summaries must be in the hands of the Secretary by the 31st January 1959.

THERMAL INSULATION CERAMIC COATINGS†

by A. V. Levy*

Marquardt Aircraft Company

INTRODUCTION

THE development of advanced performance aircraft and missile powerplants has resulted in a requirement for protection of metal components in the combustion area of the engines that extends ceramic materials considerably beyond the range of their previous applications. Frit type ceramic enamels have had considerable use in reciprocating and turbojet engines applied on components that contained hot combustion gases at temperatures below 1,800°F. They were applied in thicknesses of the order of 1-2 thousandths of an inch, furnace fired, and used to extend the life of the component by protecting the metal against oxidation and carbon pickup. The thicknesses used eliminated the brittle behaviour of solid body ceramics and permitted them to perform admirably under severe vibration conditions. The shortcomings of this type of ceramic coating were its temperature limitations and its inability to insulate as well as protect the base metal.

Advanced powerplants require ceramic coatings that specifically overcome the two shortcomings of the frit type coatings. Gas temperatures over 2,000°F require that coatings be developed that can withstand 2,000°F and above and that can be applied in thicknesses sufficient to insulate the structural base metal from severe oxidation and strength reduction effects. Two types of coatings have been developed that have successfully withstood temperatures of 3,000°F and above, markedly reduced the operating temperature of the metal components upon which they were applied, and yet have withstood the severe mechanical vibration of powerplant operation. The first insulating type ceramic coating to be successfully applied to a combustion chamber was a flame sprayed ceramic oxide. The other general type of coating is a metal reinforced ceramic that is applied by troweling a ramming mix into a metallic matrix that is attached to the structural base metal.

FLAME SPRAY UNREINFORCED COATINGS

Present status

Both powder and pressed and sintered rods of several ceramic materials have been successfully applied to suitably prepared metal surfaces by means of an oxy-acetylene flame spray gun mechanism or a detonation device that propels the coating particles at the metal surface at high velocities. The following materials have been sprayed:

(1) Alumina – Al_2O_3
(2) Zirconia – $Zr\,O_2$
(3) Mullite – $3\,Al_2O_3\,2\,Si\,O_2$
(4) Forsterite – $Mg_2\,Si\,O_4$
(5) Zircon – $Zr\,Si\,O_4$
(6) Spinel – $Mg\,O\,Al_2O_3$
(7) Chromia – Cr_2O_3
(8) Ceria – $Ce\,O_2$
(9) Titania – $Ti\,O_2$

The thicknesses of the sprayed coatings vary with the application from 0.005″ to 0.1″ and greater in special cases. A workable thickness range for these materials can be considered as 0.010″ to 0.080″ for most applications. They range in porosity from 1% to 16% depending on the method of spraying and material used. The porous, overlapping scale type structure of flame sprayed ceramic coatings gives them a mechanical flexibility that is several orders of magnitude greater than solid body versions of the same materials. The surfaces of the as-applied coatings range in smoothness from an RMS of 10 to an RMS of 250. All of the coatings can be ground to surface finishes of less than RMS 10. Table 1 presents the properties of some of the ceramic coatings either in production use or in the development stage.

Flame sprayed ceramics are in development and in some cases production use as thermal insulating and protective coatings in the following applications:

(1) ramjet engine combustion chambers
(2) ramjet engine and afterburner combustor components

TABLE 1

PROPERTIES OF FLAME SPRAYED CERAMIC COATINGS

Property	Alumina (Rokide A)	Zirconia (Rokide Z)
Composition	98.6% Al_2O_3	98%
Density — lb/cu inch	0.116	0.188
Thermal drop through 0.030″ at steady state melting temperature	6°F/0.001″	8°F/0.001″
Maximum service temperature	3000°F	4200°F
Thermal conductivity (calculated from thermal drop data) BTU/hr/ft²/in/°F at 1000°–2000°F	19	8
Emissivity 1000°–2000°F	0.3–0.4	0.3–0.4
Thermal expansion coefficient 70°–2550°F	43 x 10^{-7}	64 x 10^{-7}
Coating thickness range	0.005–0.100	0.005–0.060
Porosity	8–12%	8–12%
Hardness and abrasion resistance	very high	high
Thermal shock resistance	excellent	good
Resistance to vibration and flexing	very good	good
Application cost per square inch/0.001″	0.8–1.0¢	1½–2¢

†Paper read at the Joint I.A.S./C.A.I. Meeting in Ottawa on the 8th October, 1958.

*Supervisor, Materials and Process Section.

(3) rocket thrust chambers and exit nozzles
(4) jetevators
(5) turbine wheels
(6) burner tubes
(7) thermocouple tubes
(8) inside surface of nose cone
(9) fuel injectors
(10) graphite boosters and sustainers

For the most part, the coatings in use today are alumina and zirconia. Alumina is used where its low density can be taken advantage of and where its lower melting temperature is not detrimental. Its low emissivity is also used to advantage in combustion chambers and in other areas where high reflectivity is desired. Zirconia is used where a higher melting temperature material is needed, as in a rocket nozzle application.

Figure 1 shows a ramjet engine tailpipe coated with Rokide A.

Future

As higher reaction or aerodynamic heating temperatures are required, the use of insulating ceramic coatings will increase. The successful spraying of materials by the conventional flame spray methods other than the alumina and zirconia now primarily used will extend the application of this type of thermal insulation. The advent of higher heating sources, such as the plasma jet, will enable materials of higher refractoriness to be applied as coatings and markedly extend the application range of flame sprayed coatings. Coatings for service in the 4,000°F to 6,000°F temperature range will be possible using the plasma jet flame source.

The limitations of the flame sprayed type of insulating ceramic coatings are:

(1) maximum thickness of about 0.1" for economical, reliable service,
(2) long time, multi cycle service has not been absolutely proven, especially on sheet metal structures,
(3) melting temperatures of the materials sprayed, and
(4) limiting degree of insulation as determined by thermal conductivity and maximum thickness.

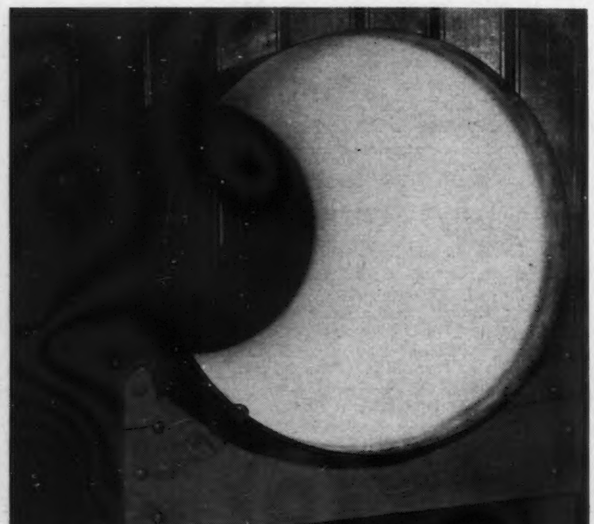


Figure 1

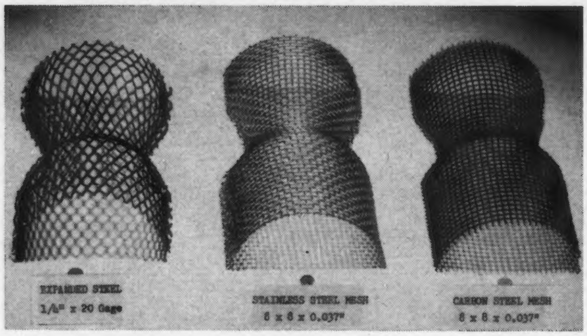


Figure 2

REINFORCED CERAMIC COATINGS

Present status

Reinforced ceramic coatings are in the advanced stages of laboratory development at the present time. Several types have been developed embodying many combinations of reinforcing media and ceramic materials.

The various types and configurations of reinforcing media being investigated are:

(1) wire mesh made from mild steel, 300 series stainless steel, and molybdenum,
(2) expanded metal made from mild steel, 300 series stainless steel, and molybdenum,
(3) corrugated metal strips made from mild steel, 300 series stainless steel, and tantalum,
(4) fibers of ceramic material, primarily aluminum silicate and quartz randomly oriented in ceramic matrix and laminated throughout matrix.

Figure 2 shows nozzle segments formed from mild steel and type 304 stainless steel wire mesh and expanded metal.

The types of ceramics being reinforced are:

(1) sodium silicate base composites containing various refractories, such as alumina, mullite, kyanite, silica
(2) phosphate bonded alumina, zirconia, chromia
(3) pure alumina, zirconia

The continuous network reinforcements, such as wire mesh and expanded metal, are required both to reinforce the coating and to provide a means of firmly anchoring the coating to the base metal. They are brazed or resistance welded to the base metal prior to application of the coating. The fiber metal and ceramic reinforcements are mixed into the ceramic mixture prior to application. In the case of the molybdenum continuous network reinforcements, the reinforcement and base metal can be oxidation resistance coated prior to application of the insulating ceramic.

The ceramics are applied by two methods — flame spraying, as in the case of the pure alumina and zirconia, and by troweling, as in the case of the phosphates and silicates. In general, the reinforced ceramic materials presently being investigated for coatings do not require a high temperature firing prior to service. The flame spray coatings can be used in the as-applied condition; the trowel coatings usually require a baking cycle at 800°F or less.

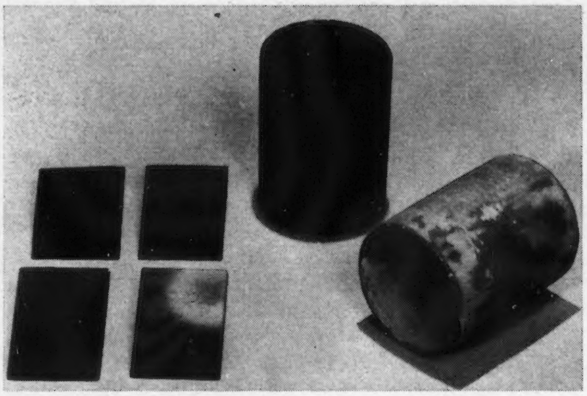


Figure 3

Figure 3 shows several small test panels and two test cylinders of reinforced ceramics. The properties of reinforced ceramics fall into the general performance specification as follows:

(1) withstand at steady state conditions temperatures in the range 2,500°F-4,000°F,

(2) provide thermal drop through the system at steady state heat flux of 10,000 BTU/sq ft/hr or greater of approximately 10°F per 0.001″ for material exposed to heat on one side only,

(3) have thermal conductivity, k, in range 5-10 BTU/sq ft/in/hr/°F,

(4) have system density of the order of aluminum (0.10-0.14 lb/cu in),

(5) be capable of withstanding severe mechanical vibration, flexing, thermal shock, and recycling,

(6) provide a means for firm attachment to a structural sheet metal, developed surface wall,

(7) require no high temperature firing for service,

TABLE 2

PROPERTIES OF REINFORCED CERAMIC COATINGS

Property	Aluminum Phosphate Bonded Alumina	Zirconium Phosphate Bonded Zirconia
Density of ceramic plus reinforcement	0.10–0.12 lb/cu in	0.14 lb/cu in
Thermal drop through 0.125″ at steady state	8°F/.001 inch	10°F/.001 inch
Maximum service temperature	3500°F	4000°F
Thermal conductivity (calculated from thermal drop data) BTU/hr/ft²/in/°F at 2400°F	7.2	6.0
Emissivity at 3000°F (may be modified by formulation change)	0.2	0.3–0.4
Reinforcement metal	Mild Steel, Stainless Steel, or Molybdenum	Molybdenum
Curing temperature	800°F	800°F
Mechanical strength	Excellent	Good
Thermal shock resistance	Excellent	Excellent
Recycling capability	Excellent	Fair
Resistance to vibration and flexing	Excellent	Good
Coating thickness	0.1″–1″ Plus	0.1″–1″ Plus
Type of use	Coating or Structure	Coating or Structure
Material and fabrication cost	Low	Low

(8) have low material and application cost,

(9) deposit to total thicknesses from 0.1 to 0.5 and greater inches, and

(10) provide for emissivity selection from 0.2 to 0.8.

Table 2 lists the properties of two typical reinforced ceramic coatings.

Reinforced ceramic coatings have been thoroughly flame tested in the laboratory in single and multi-cycle exposures. They are presently undergoing mechanical tests to determine mechanical properties. Accurate determinations of their physical properties are also underway in the laboratory. They have been evaluated in full scale engine combustion chamber operation and have shown considerable promise, both from a toughness and durability standpoint and from their thermal insulation capabilities.

Reinforced ceramic coating development has been accelerated by the opportunity to readily change from 2″ × 3″ flat coupon testing to testing under full scale engine operating condition in as little time as a single week. Many structural ceramic development programs in the past have failed because no satisfactory simulated service test was used during the composition development to determine how well the material stood up under combined heat, thermal stress and mechanical vibration. Considerable laboratory effort was therefore expended refining a material system that would not stand up in the application. Because small scale and full scale tests were run all during the development of reinforced ceramic coatings, blind alleys were quickly determined and the necessary backtracking done before a great amount of time had been wasted. It is felt that this factor was of utmost importance in developing the reinforced ceramic concept to its present state. Figure 4 shows the laboratory flame test setup used to screen new compositions and reinforcements configurations and determine some of their critical thermal properties.

Figure 5 shows how effective a reinforced ceramic coating is in providing thermal lag and steady state temperature reduction in a panel of N-155. In this test, the oxy-acetylene-air torch was set to heat a bare panel of N-155 0.050″ thick to 2,100°F in 30 seconds. Using the

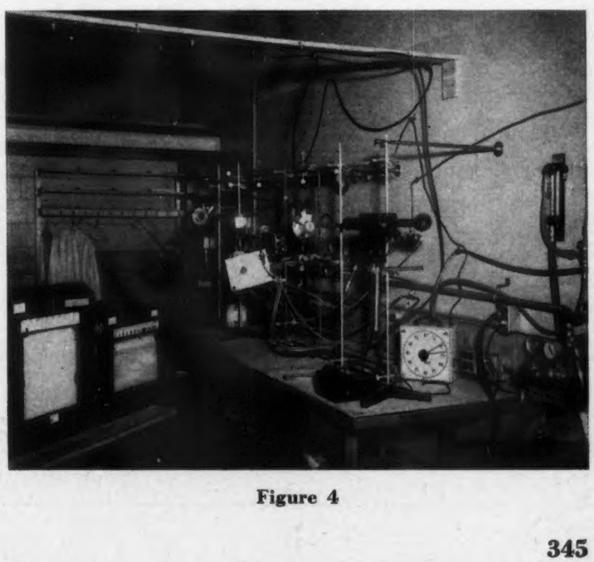


Figure 4

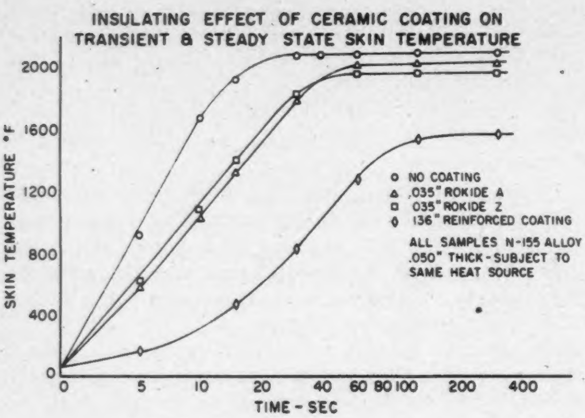


Figure 5

same torch settings, panels of Rokide A and Z coated N-155 and reinforced ceramic coated N-155 were tested. It can be seen that the 0.030" of Rokide A (alumina) and Rokide Z (zirconia) provided a temperature lag in the N-155 of 400°F for 30 seconds and reduced the steady state temperature by 100°F. 0.136" of reinforced ceramic coating provided as great as 1,500°F temperature lag for up to 40 seconds and reduced the steady state temperature of the metal by 500°F. The gas temperature and heat flux used in this test were below those actually experienced in ramjet combustion chambers. Under actual operating conditions, especially for the higher heat fluxes experienced, even greater thermal insulation is provided.

Future

Reinforced ceramic coatings of sufficient thickness to result in temperature reduction in the outer, load carrying metal structure at steady state operation of several hundred degrees must be extended to higher operating temperatures. The present surface operating temperature maximum of 4,000°F will have to be extended to 5,000°F and above if these coating systems are to keep up with some of the advanced powerplant concepts. The use of the plasma-jet high temperature source for depositing higher melting temperature materials, either in the form of full coatings or only as surface coatings over a lower melting temperature base material, should extend this type of coating to higher temperature operation.

Refinements in application techniques and in reinforcement configuration are also fertile fields for further development. The evaluation of reinforced ceramic coatings in various applications is also needed in the near future to effectively draw these materials out of the laboratory.

ACKNOWLEDGMENT

This research was supported in whole or in part by the United States Air Force under Contract No. AF33-(616)-5441, monitored by the Materials Laboratory, Wright Air Development Center, Wright-Patterson Air Force Base, Ohio.

STATISTICAL QUALITY CONTROL IN AIRLINE MAINTENANCE†

by H. G. Packer*

Canadian Pacific Air Lines, Limited

SUMMARY

Quality control in airline maintenance is as old as the industry itself, but the application of statistical procedures to quality control work is a more recent innovation. The basic aim of quality control work is to improve product reliability. "Reliability" is defined as the probability that a particular component or system of components will do what it is supposed to do, under operating conditions, for a specified operating time. The application of the probability multiplication law, and its effect on reliability, can increase efficiency of the prediction of a part or component failure. Statistical quality control work in airline maintenance can show the greatest benefit in increased safety, improved procedures and lowered costs when applied to prevention of defects or premature removals.

All measurements are characterized by variation, which is due either to chance or to an assignable cause. A process is considered "in control" when variation does not exceed a previously established "chance" level. Based on data obtained from a short period of operation, the level of chance variation in the process of producing serviceable airplane flying hours can be calculated and control limits established.

Charts can be constructed which clearly show when, where, and for what reason the control limits are exceeded, and investigation and corrective action can be initiated.

Many other applications of statistical procedure are possible and the subject is important enough to warrant considerable study by experts in the Airline industry, so that an even broader application of statistical procedures will be possible.

INTRODUCTION

EVERYONE in the various fields of aircraft production, operation and maintenance, knows that quality control is as old as the industry itself. (Inspection intensity up to 300% is not unusual.) However, in this paper I would like to discuss some aspects of the application of statistical procedures to quality control work in airline maintenance.

This is a recent application to our work which is becoming increasingly important. First, I must make it clear that I do not attempt to speak as an authority on the subject. Much work has been done in the field of statistical quality control in airline maintenance, and much remains to be done. At Canadian Pacific Air Lines, we have studied some of the methods and procedures involved, and I believe we have found ways to apply them to our operation with definite benefit.

It is most important to bear in mind that in statistical quality control there is certainly no substitute for experience — you cannot hope to set up a series of control charts, limits, sampling plans etc, based on some other operator's experience. No matter how short the period covered, data obtained from the operating experience of the company involved forms the only basis for a statistical approach to quality control.

Most of us are familiar with the old saying that quality cannot be inspected into a product, but must be designed and built into it. Similarly, quality cannot be inspected into aircraft performance; it must be designed and built into the aircraft *and its components*, and must be *maintained and improved* by careful and proper operation, servicing, repair and overhaul.

Basically, in quality control work, we are trying to improve the reliability of our product, in whatever branch of industry we happen to find ourselves.

Let's take a second look at that sentence — what is Reliability?

RELIABILITY

Ask three of your friends how they define "reliability", how much is needed, and what steps should be taken to obtain it, and you'll be surprised at the variety of answers you receive. So, let's start off with a definition of reliability that is gaining the most common acceptance in the technical field.

"The reliability of a particular component or system of components is the probability that it will do what it is supposed to do under operating conditions, for a specified operating time."

This looks simple enough, but does present certain hazards.

PROBABILITY

The first important challenge is that word "probability" — it takes you seriously into the field of data collection and statistical analysis. To get an idea of the significance of probability, picture a chain, with its successive links.

Now, as we all know, that chain will be only as reliable as its weakest link. Moreover, statistically, the overall reliability of the chain (or system) is the mathematical product of the reliabilities of the individual links, expressed as . . .

Overall Reliability, $R_o = r_1 \times r_2 \times r_3 \; . \; . \; . \; . \; r_n$

As an example, assume a product has a chain of 100 components, in which each component has a reliability of 99% — which assumes that only one of a hundred units of each component will fail.

†Paper read before the Vancouver Branch of the C.A.I. on the 18th March, 1958.

*Maintenance Methods Analyst.

These are relatively high standards, but past production has established that they can be achieved. But what happens to the product or system? Multiplying .99 by itself 100 times ($.99^{100}$), note that our chain of components will have a reliability of only 36.5%! Two out of three of our chains will probably fail.

As another example, let's look at contacts in a multi-contact electric connector. If, for instance, we are to assemble connectors containing 25 similar contacts from a 1% defective contact population, we can expect 22% of the connector assemblies to contain one or more defective contacts!

So when we multiply the probabilities of thousands of parts and pieces, hundreds of components and a dozen or more systems in a modern aircraft, the probability of a defective part or premature removal becomes almost a certainty!

Thus, the multiplication of probabilities presents a major challenge to the designer, the manufacturer and the user of the final product.

All of us concerned with materials, parts or components must constantly keep in mind:

(1) the probabilities,
(2) what the part is supposed to do,
(3) the operating conditions, and
(4) the time it must operate satisfactorily.

In the aircraft industry, I believe it can be said that the last three factors of our "reliability formula" have usually been recognized and properly controlled. This leaves only the probabilities to be adequately controlled.

In its application to airline maintenance, statistical quality control can show the greatest benefit in increased safety, improved procedures, and lowered costs when applied to prevention of defects or premature removals. The prevention of defects is accomplished through (1) the use of process control techniques where practicable, (2) the development of a high degree of quality consciousness on the part of all personnel, or (3) simply through the accumulation of historical records showing the extent and nature of the defects occurring.

In the latter case, analysis of the history record must be performed in an attempt to locate the area or areas producing the most expensive defects.

VARIATION

Every measurement, either quantitative or qualitative, is characterized by variation. The total amount and direction of this variation, and the dispersion of the many values about an average or mean value, determine the type of variation.

Statistical theory and practice have established that the different types of variation can be classified as following a specified "frequency distribution" pattern, which has specific characteristics.

All variation is made up of two kinds: (1) random or chance variation, and (2) non-random or assignable variation. Chance variation is brought about by so many different contributing factors, many of which we could not change in any way even if we knew the causes, that for all practical purposes we can consider it as inherent variation of the process or product. Our process is considered "in control" when variation does not exceed this level. Assignable variation is due to some definite cause or group of causes which we should be able to track down and correct.

THE PROCESS

In the case of premature removals then, the problem is to find out what number (or percentage or rate) of removals is due to chance causes, and what is due to assignable causes.

In manufacturing, process control is judged by inspection of the product. In airline operations, what is the process, and what is the product? The process can be considered to be all the servicing, maintenance and overhaul operations required to produce serviceable airplane flying hours. And the product is that same serviceable flying hour, in past practice usually taken as a block of 1,000 flying hours.

So let's get down to cases. We must count, at regular intervals, the number (or rate) of premature removals occurring in each 1,000 hours of flying. The interval usually considered is one month, and the rate per 1,000 hours for each period is generally used in preference to number of removals.

Once the data are collected, we must arrange them in some way that will reveal aircraft performance (quality of product). One of the earliest measures of aircraft performance was the performance curve. This curve expresses performance in terms of "Number of Premature Removals per Thousand Hours Flown". This is just what we're looking for, but in the past we have relied upon individual judgment to determine whether or not the monthly fluctuations were large enough to warrant investigation; it was a matter of personal opinion, influenced by the experience of the individual interpreting the curves, as to whether or not the curve was out of control and required investigation. The addition of control limits to the performance curve eliminates the personal opinion (human) element.

CALCULATIONS

The calculation of control limits involves true statistical procedures. It can be shown that each "variation family" or type of distribution will obey fixed mathematical laws, with known degrees of certainty. One of the most valuable parameters for judging a distribution of data is the Standard Deviation, usually denoted by the Greek letter sigma (σ). The concept of Standard Deviation is rather difficult to explain. Those of you with engineering training will probably recognize it as the Root-Mean-Square Deviation. For the rest of us, it is best thought of as a unit of measurement of the dispersion of the variation about the sample average, or mean. Actually, it is the distance between the mean and a point of inflection (where the curve changes from concave upward to concave downward) of a "Normal Curve". (For those interested, a very complete description of Standard Deviation is to be found in "*Statistical Methods in Quality Control*", by Dudley J. Cowden[1].)

The Normal Curve (see Figure 1) is a graphical representation of one of the previously mentioned "variation families" or types of distribution, called the Normal Distribution. This distribution is important be-

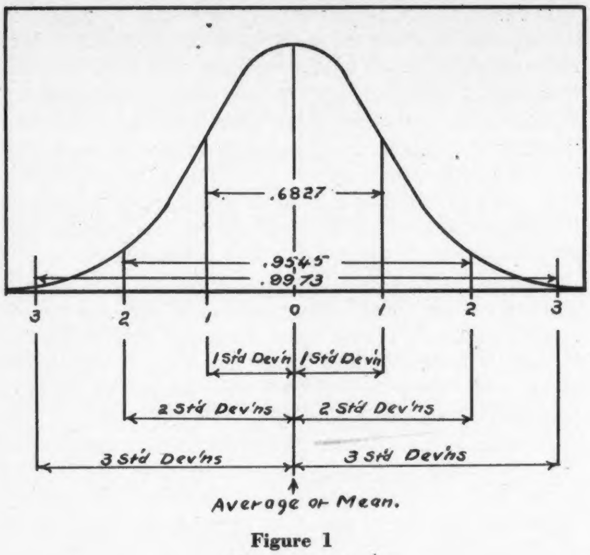


Figure 1
Normal curve

cause many kinds of distributions of samples from controlled processes do not depart significantly from the Normal form. The sizes of two completely different objects (even those measured in different units) can be compared if they are stated in terms of deviations from the means of their respective distributions, in units of the standard deviations of their respective distributions. Even more important is the fact that most theoretical distributions approach the Normal form under certain conditions.

Figure 1 shows the rough picture of the characteristics of a frequency distribution which can be formed from the knowledge of only two parameters – mean and standard deviation. Fortunately, in the type of distribution involved in "C" chart work (see Figure 2), we find the *variance* of the distribution is equal to the *mean*. We also find in the mathematics of statistical work that the standard deviation is the square root of the variance, so that to obtain a value for the standard deviation of our distribution, we need simply to take the square root of the mean.

This is perhaps oversimplified, but the important point to bear in mind, as shown in Figure 1, is that limits of one unit of Standard Deviation (1σ) on either side of the mean, will contain 68% of the chance variation encountered; limits of 2σ will contain 95.5%, and limits of 3σ will contain 99.7%. To put it another way, with control limits at 1σ, we expect the limit to be exceeded, by chance, 32 times in 100; with limits at 2σ, we expect the limit to be exceeded 5 times in 100; and with limits at 3σ, we expect the limit to be exceeded by chance only 3 times in 1,000.

CONTROL LIMITS

Now the control limits must be located in such a way that the investigator will usually look for serious trouble and not waste his time on wild goose chases. The control limits are supposed to strike an economical balance between two kinds of errors, (1) looking for trouble that does not exist, and (2) failing to look for trouble that does exist. Neither of these errors should be unduly large, yet neither should be reduced to such an extent that it unduly increases the other.

Since we want our control limits to give advance warning of impending trouble, yet meet the foregoing requirements, we set them at 2σ. For the advantage of advance warning, we feel that we can afford to be wrong one time in twenty, or 5% of the time. In addition to this, we will be "wrong" in the right direction – we will be looking for a cause of trouble when no trouble actually exists. Also, since we have records for each premature removal, we are in a favourable position to judge quickly whether or not there is an assignable cause for an out-of-control condition. Finally, an out-of-control condition for two consecutive months at 2σ control limits gives a slightly higher probability of an assignable cause than one month out-of-control at 3σ limits, and provides one month's advance warning.

The mathematics involved in calculating the control limits are simple, and if many control charts are to be drawn, a chart called a nomograph can be constructed, based on the established statistical formula for the type of distribution involved, which allows control limits to be read off with no calculation.

CONCLUSIONS

The advantages of all of the preceding are perhaps obvious, but some of the more important ones are:

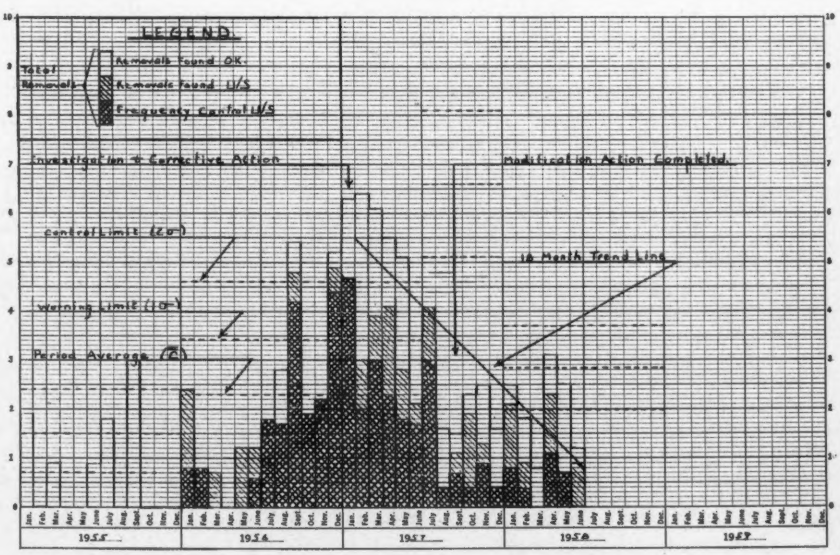


Figure 2
A control chart

(1) For each operator, there is a level of premature removals which can be considered as inherent — this method clearly indicates that level.

(2) When the above level is exceeded, the operator can be sure, within clearly defined limits of certainty, that the excess is due to an assignable cause.

(3) Trouble spots are quickly brought to light so that investigation and corrective action can be promptly initiated.

(4) *All* factors contributing to variation are included, and specified factors can be spotlighted for special observation.

(5) Analysis of data is facilitated, so that comparisons and forecasts can be made with ease and reasonable accuracy.

This, then, is the basic application of statistical quality control to airline maintenance. As experience is gained, other more complex procedures can be instituted to take advantage of probability sampling, analysis of variance, significance and reliability tests, work sampling etc.

An example of the application of control chart technique is given in Figure 2. An out-of-control situation developed during the last half of 1956. Investigation revealed the major source of trouble to be related to parts involved in a recent manufacturer's modification, and incorporation of this modification together with some other changes was recommended. Control lines for the last half of 1957 were exceptionally high, since the period of operation from which performance data were obtained included the period of high failure rate.

Following completion of modification action, performance returned to a satisfactory level and control lines for 1958 were considerably lowered. Though not shown on the chart since the situation at present does not warrant it, much of the variation around the middle of 1958 is due to bearing troubles, which are increasing.

One recent application we have made of probability sampling is a simple random sampling plan of inspecting aircraft at trip departure for condition of specified non-airworthiness items which govern passenger appeal. In this application, the trip numbers are randomized and each inspection is carried out on a prescribed form.

Results of this sampling procedure are periodically notified to the Department responsible for taking corrective action. We have been operating this procedure for about 8 months and the outstanding characteristic of it is the great improvement in quality of interior passenger-appeal items on despatched aircraft.

I hope I have been able to give you some insight into the possible applications of statistical quality control in our industry. The situation is complex and requires considerable study to enable an even broader application to the airline industry. It is a specialized application of statistical procedures with tremendous possibilities, and it warrants considerable study by specialists in the field. A statistician could teach us all about statistics but, when it comes to the solution of our problems through the application of statistics, it is up to us to become the experts.

ACKNOWLEDGMENTS

The author wishes to acknowledge the work done in this field by Mr. Allan M. Hull and his associates, of United Air Lines.

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AEROBALLISTICS RANGE MEASUREMENTS OF THE PERFORMANCE AND STABILITY OF SUPERSONIC AIRCRAFT†

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SUMMARY

This paper describes a method of measuring aircraft drag and stability characteristics in free flight. Tests have been made firing scale models of existing delta- and straight-winged aircraft into an aeroballistics range at supersonic speed and high Reynolds number. Histories of the model's speed, attitude angles and lateral motion during the flight are obtained using light screens and yaw cards, while shock wave and flow behaviour are observed with schlieren systems. Either a longitudinal or a lateral type of motion during the flight can be obtained by suitable adjustment to the model's ballast and its position in the launching sabot, thus enabling simplified methods of analysis to be used.

Longitudinal and lateral dynamic and static derivatives so far obtained using this method have compared well with values obtained in high speed wind tunnels and with large scale rocket launched free flight models. Extensions of the present technique, in terms of size and speed of the model, and development of instrumentation to obtain additional aerodynamic data are discussed.

INTRODUCTION

The technique of obtaining aerodynamic information from aeroballistics range measurements has been used successfully at such establishments as the Canadian Armament Research and Development Establishment (CARDE) and the Ballistics Research Laboratories[1] for several years for missiles and ballistic projectiles. The accuracy of the results obtained and the inherent simplicity of the method have led more recently to the use of the range at CARDE for tests on a wider variety of shapes[2, 3], including delta wings, spheres and aeroplanes. The present report describes the progress that has been made with various aeroplane models in the aeroballistics range, including the Avro CF-105, the Bell X-1 and a simple aspect ratio 2 delta-winged aircraft.

The basic test equipment was that in general use at CARDE for testing missiles and ballistic shapes, the aircraft being launched at supersonic speed from a 5.9 inch smooth-bore gun by means of a sabot carrier. The sabot is discarded at the entrance to the range and, for the first 400 ft of the model's free flight down the range, measurements are taken with the aid of velocity-measuring light screens, schlieren photography and yaw cards. The latter, consisting of sheets of paper mounted at 2½ ft, 5 ft and 10 ft intervals down the range, are punctured by the model in its free flight. By subsequent measurements of these cuts, the model's angles of pitch, roll and yaw, as well as the lateral position of its centre of gravity with respect to the line of fire, can be determined.

A description of the method, with particular reference to the problems encountered in model manufacture, launching and measurements, will be followed by a discussion of the type of results obtained and the methods of analysis which can be used on them and, before concluding, some of the limitations of the method and plans for the future will be discussed.

Although some aeroplane tests have been carried out at BRL and at NACA[4], this was the first time an aeroballistics range had been used for a comprehensive program of tests on models of existing aircraft. Some mention of the reasons for undertaking the study may therefore be of interest. With the present trend in aircraft design to thin, highly-loaded wings of short span and long thin fuselages, there is an increasing need for knowledge of dynamic characteristics, particularly cross-coupling effects, even at an early stage in design. Alternative methods for obtaining this information heretofore have been by estimation, by wind tunnel tests[5] and by ground-launched, rocket-boosted free-flight models[6, 7].

Methods of estimation or calculation are subject to large errors because they are frequently based on an extrapolation to high Mach number of theoretical or experimental low speed data and because even slight configurational differences from a similar aircraft could have a large effect on values of some of the derivatives, such as C_{n_p} and C_{l_r}.

Wind tunnel methods have been devised for measuring a few of the dynamic derivatives, and good accuracy has been obtained in the determination of $C_{M_{\dot\alpha}} + C_{M_q}$, $C_{L_{\dot\alpha}} + C_{L_q}$, and C_{l_p}[8]. The equipment used to oscillate the models and to analyze the results can be

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quite complicated and costly, however, and the methods are unsuitable for the determination of cross-derivatives. The use of a free-flight technique eliminates the need for the sting support used in the wind tunnel and so avoids the errors due to sting and support corrections. This is patricularly important in the measurement of aircraft drag. Tunnel wall corrections, which are difficult to allow for accurately, especially in transonic wind-tunnel tests, are also eliminated. As either aeroballistics range tests or ground-launched tests are done at or near sea-level density with full scale Mach number, the Reynold's number is in general higher than with wind tunnel tests. For the CARDE tests at Mach 2.0 the Reynold's number was 3.8 million based on mean aerodynamic chord.

The most obvious advantage of the free flight tests is the ability to observe the complete three-dimensional dynamic behaviour of the model with no restrictions applied to it. The method of ground-launched model testing using ground tracking equipment and telemetry to record test data is a well-proven technique from which all the necessary test information can be obtained. Its chief drawback is that, because of the size and complexity of the model and the amount of preparation and cost necessary for each test, it does not lend itself either to a quick appraisal of a number of different configurations or to a long program of numerous tests on a single configuration.

It is because of the need for such a quick appraisal in early design work, or a full program to complete a final design evaluation, that the two main advantages of the range technique over the ground-launched method are important. These are the simplicity of the instrumentation and the small size and cheapness of the model itself. Because measurements are made externally, the model carries no instrumentation, but requires only to be dimensionally accurate and suitably ballasted. The basic instrumentation required in the range is no different to that used for missile and projectile testing and provides a much cheaper and quicker means of obtaining dynamic information than by the use of airborne telemetry. This being the case, the type of test reported on here could be envisaged as forming a part of the preliminary testing of an aircraft design complementary to the first wind tunnel tests, and at a sufficiently early stage in the aircraft's development that configurational changes specifically to improve the dynamic characteristics could still be made.

TEST METHODS

General

The problems concerning the aeroballistics range testing of aeroplane models may be logically divided into the following broad headings:

(a) Manufacture of the model must be to sufficient accuracy to adequately simulate the geometry of the original aircraft and must be with sufficient strength to withstand the high acceleration loads from the gun during launch. The method of construction must be suitable for the addition of ballast when necessary and cheapness of manufacture is also desirable in view of the "one-shot" nature of the tests.

(b) Prior to firing, dimensional measurements of profile and planform must be made on the model to ensure the accuracy of its geometry and for reference later in yaw card reduction. Measurements of the model's centre of gravity positions and the moments and product of inertia must also be taken.

(c) The sabot used to launch the model must provide accurate location of the model with respect to the line of fire, must impart the necessary acceleration to the model without damaging it, and must separate cleanly outside the barrel, allowing the model to fly on into the range with no more than the desired disturbance in pitch or yaw.

(d) Once the model is in the range, observation of its location, attitude angles and velocity must be made with sufficient frequency and accuracy to provide a useful record for analysis.

(e) Methods of analyzing the records must be devised to determine the necessary stability and performance parameters.

The first four of these items will be considered in turn in the following sections, and the analysis methods will be discussed later.

Methods of construction

Figures 1 to 4 show some of the aeroplane models that have been tested in the range. The NRC delta is an aspect ratio 2 model with an NACA 0003-63 aerofoil section and a 5 inch span. This configuration is currently being tested in the wind tunnel of the High Speed Aerodynamics Laboratory of the National Aeronautical Establishment at Ottawa for damping in roll and damping in pitch, using a free oscillation half model technique.

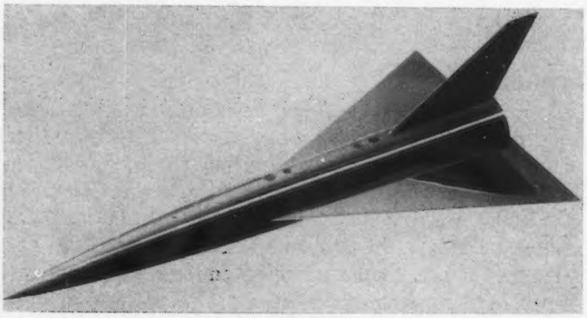


Figure 1
NRC delta model

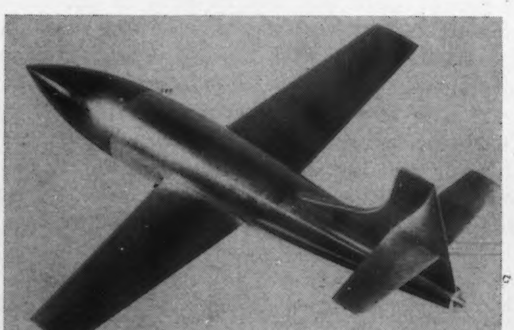


Figure 2
Bell X-1 model

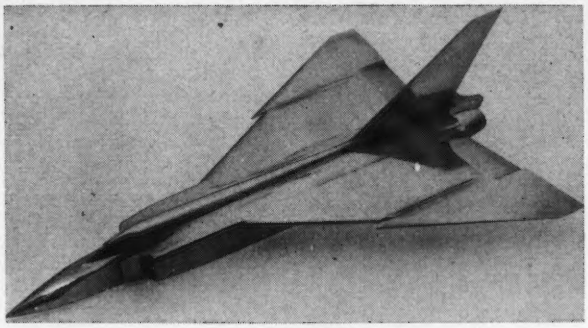


Figure 3
Avro CF-105 model, front view

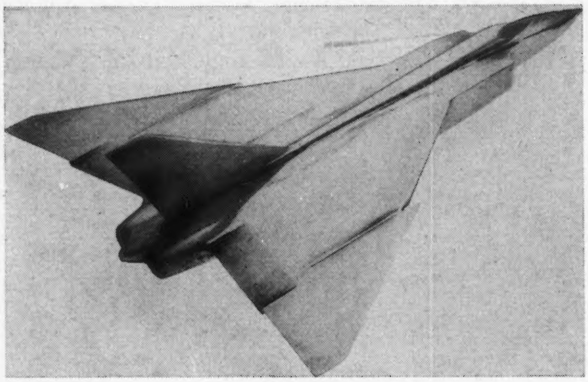


Figure 4
Avro CF-105 model, rear view

As static lateral and longitudinal stability derivatives are also being measured in the wind tunnel, the model has been chosen as a means of "calibrating" the range technique to determine the accuracy of the results, and for general development of methods of manufacture, measurement and analysis. The Bell X-1, with a 5.6 inch span, is 1/60th full scale. The model shown, which was a preliminary test model, was made without some of the fuselage detail to simplify manufacture. The Avro CF-105 models are 1/120th scale, with a wing span of 5 inches, and have been made in aluminum, brass and steel.

Of these models, the most complicated to produce has been the CF-105 and so a description of the methods used in its manufacture will embrace most of the problems that have arisen.

An important factor in the feasibility of aeroballistics range tests with such models is the accuracy and cheapness of their construction. In general, the surface finish and accuracy of profile should be up to the standard of high speed wind tunnel models; however, with no method of recovering the models a large number of them may be required, depending on the scope of the test program.

The method used at CARDE is a good compromise between these conflicting requirements. Master copies are first made of both top and bottom surfaces of the model, as shown in Figure 5, with suitable reference surfaces to establish the height and position of the fuselage datum. These masters are copied from a wind tunnel model using a Deckel Pantograph Die-sinker and are 1½ times the model scale. The contours from the two masters are then transferred on to the top and bottom surfaces of a prepared blank, again using the Die-sinker, to form the model. This blank is made up of two pieces joined by a 10-24 stud so that after the external form has been machined the nose portion of the model can be removed, as shown in Figure 6, to facilitate the machining of the engine ducts and to enable ballast materials to be inserted in the nose. The external shape is completed by inserting and gluing in place the tab carrying the vertical fin and rudder and hand polishing all external surfaces. The accuracy of profile attainable with this method is of the order of $\pm$ 0.002 inches and the finished models can be produced at a rate of less than 100 man-hours each, once the master and templates have been made. By way of comparison, the typical cost of a wind tunnel model of similar scale is about $50,000, while for a large free-flight model, with full telemetry, the cost could be double this figure. Models of the latter type would of course be able to supply a wider variety of information than can presently be obtained from the

Figure 5
CF-105 copying masters

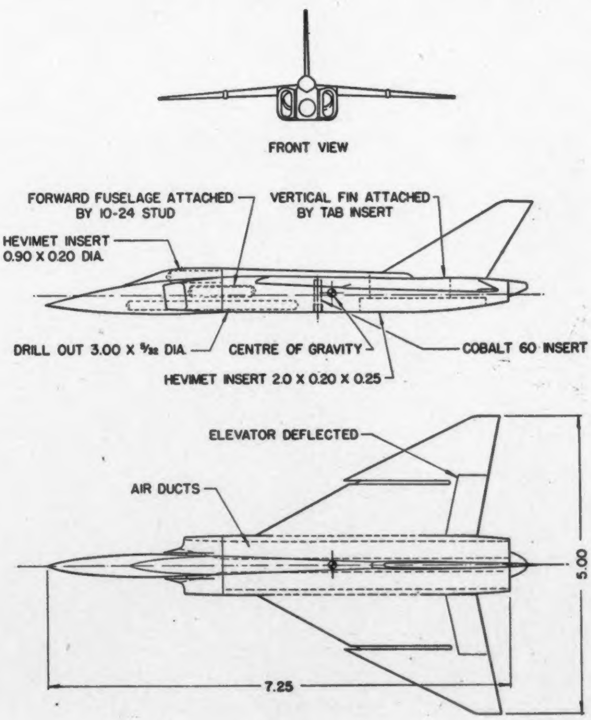


Figure 6
Details of construction of CF-105 model

simple CARDE models. As a means of reducing the cost and manufacturing time further, alternative methods of investment casting, using the lost wax process, were also investigated.

The elevator control deflection, as shown in Figure 4, is machined integrally with the rest of the wing at an angle which will trim the aircraft to fly at a small lift coefficient during its flight. One convenience of the copying method of manufacture is that for such features as the elevators, whose deflection may differ from one round to the next, changeable inserts can be used in the master with no increase in the time for manufacture. This would also simplify the incorporation of a series of changes to study drag or stability effects.

Typical ballast arrangements are shown in Figure 6 and will be discussed later. To locate the models in the sawdust butt for inspection after firing, a 2 millicurie source of Cobalt 60 was used. Although not large enough to cause handling difficulties, it provides sufficient radiation to enable the model to be located at a range of 25 ft using a directional Geiger counter.

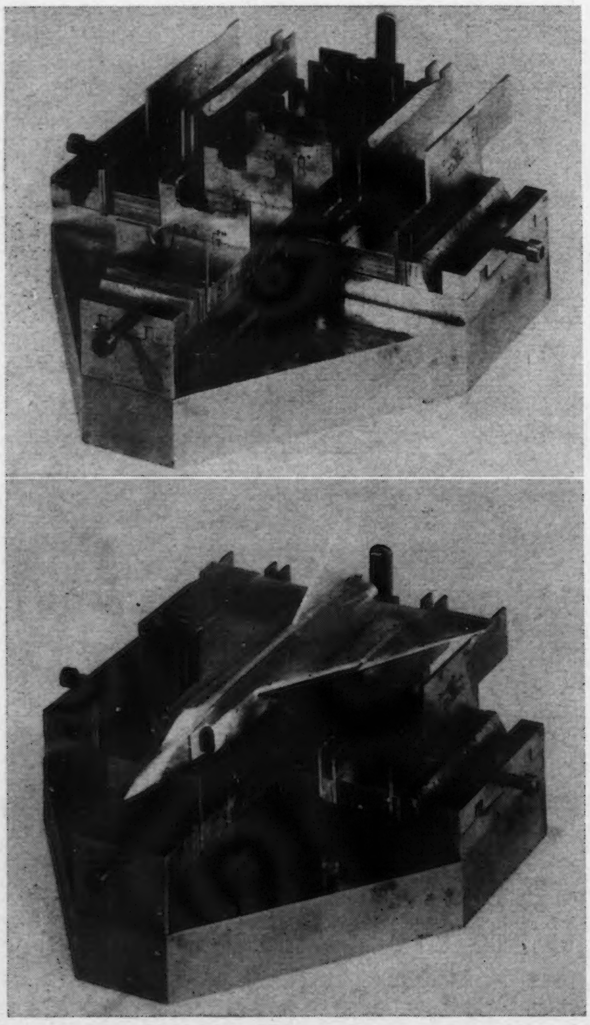


Figure 7
CF-105 template jig

Pre-flight measurements

Under this heading, there are three types of measurements — those of the model's planform and profile dimensions, of the centre of gravity location and of the moments of inertia and product of inertia.

Planform dimensions, together with certain height measurements of the wing-tips, nose etc, are required for determination of wing area, mean aerodynamic chord length and position, and for use in yaw card reduction. To obtain these dimensions, the model is supported by an angle plate in various attitudes with a height gauge used to take the measurements.

Profile measurements, for example on wing chord sections, require a more involved arrangement because of

(a) the need for establishing the spanwise and longitudinal position of the chord being measured, and
(b) the need for a large number of points to be measured in order to define the profile.

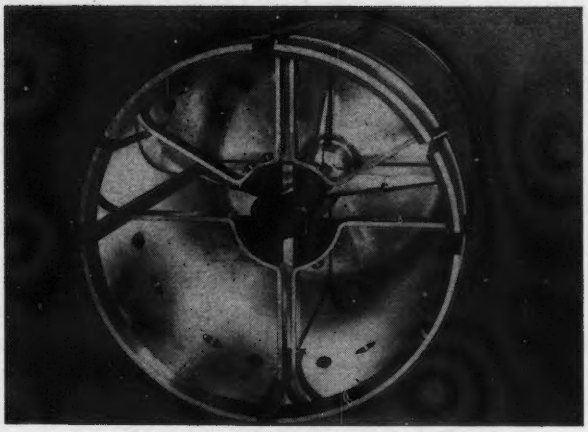
In the case of the CF-105 models, these profiles were checked with templates using the template jig shown in Figure 7. With this jig, the templates for several wing lower surface profiles and fuselage sections are held in their proper relative position so that, when the model is put in place, all sections can be checked simultaneously. Mating upper surface templates are used to check the upper surface profiles and any of the templates can be removed for carrying out independent checks during manufacture.

A second method, which is being used on the CF-105 and the NRC delta models, is to locate a number of points along each of several chord positions by using a marking template which consists of a pre-drilled plate that fits over the wing and allows marks to be made at exact locations on the wing upper surface. The height of these upper surface points relative to the fuselage datum and the thickness through the wing can be compared with the corresponding values from drawings or geometry reports and the accuracy of the profile thereby determined. As noted earlier, the error of the wing profiles, as measured in this way, is about ± 0.002 inches.

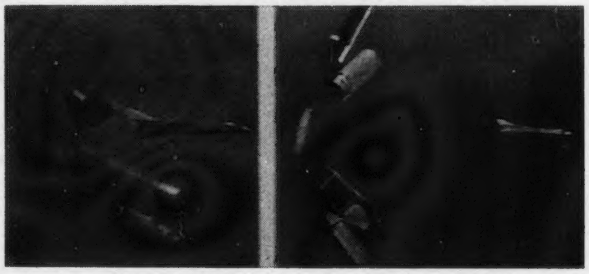
The methods for measuring centre of gravity positions and moments of inertia have been described in Reference 9, and will therefore be mentioned only briefly here. Using a knife-edge fixture, with a precision null-reading balance, the longitudinal and vertical location of the centre of gravity is determined to within ± 0.002 inches. The moment of inertia in roll and the inclination of the principal longitudinal axis of inertia below the fuselage datum, ϵ, are found by measuring oscillation periods when the model is suspended nose-down from a torsion-wire and allowed to swing as a torsion pendulum. The product of inerta I_{xz} is calculated using the value of ϵ so determined. Moments of inertia in pitch and yaw are measured by timing the model's period of oscillation about a knife-edge fitting attached to the base of the fuselage. Moments of inertia determined using these methods are accurate to $\pm 0.3\%$ and ϵ can be measured to $\pm 0.2°$.

Launching

The method used to launch models of this type into the range, using a sabot carrier, is common to most



(a) CF-105 model in sabot



(b) Separation of sabot from model

Figure 8

aeroballistics tests on aerodynamic shapes. The sabot holds the model in the correct attitude relative to the barrel of the 5.9 inch gun and, during its travel down the barrel under the action of the gas pressure, it accelerates the model to a speed slightly in excess of the test Mach number. A typical acceleration is 6,000 g's for a muzzle Mach number of 1.6 and although this is a peak value which will last for less than a millisec, the thrust pad in the sabot must provide the maximum contact area for such models as the CF-105 where the model's base area is reduced because of the air ducts. The thrust pad must also be designed to split apart, as the sabot discards, without disturbing the model. In Figure 8a the CF-105 model is shown in position in the sabot, and in Figure 8b the separation of the sabot petals can be seen at positions 20 ft and 30 ft from the muzzle with the model at about $M = 1.6$. These pictures were taken during a test at BRL, using the smear technique with a 35 mm Fastax camera. Just beyond the position of the last picture the sabot pieces strike an armoured wall, while the model proceeds into the range through a central 12 inch diameter hole.

In-flight measurements

The general arrangement of the range is shown in the model pictured in Figure 9. The sabot and model are fired from the gun emplacement at the upper right, and after the model passes the sabot trap it first travels through an entrance room where micro-flash photographs of it can be taken; then into the range proper where schlieren or shadowgraph pictures are taken, and model trajectory and attitude angles are measured at each of the 80 yaw card positions down the range.

Velocity measurements are made by a system of light screens (not shown in Figure 9) accurately surveyed at 50 ft intervals and connected to chronographs which measure the time of travel between successive light screens to the nearest microsecond. The accuracy of this method is approximately 0.3 ft/sec, in 1500 ft/sec. Model retardation values, which are obtained by differencing successive velocity readings, are therefore subject to an error of about 2% with aluminum models.

Four schlieren stations are currently used, three with 16 inch mirrors, and one with 36 inch mirrors. In Figure 10 typical schlieren and shadowgraph pictures are shown for the Bell X-1 and the NRC delta models. The amount of detail of shock wave and flow behaviour is equivalent to that obtainable with a wind tunnel schlieren system, but with the advantage of showing the complete pattern with no interference from walls or stings.

Yaw cards are normally spaced at 5 ft or 10 ft intervals, although 2½ ft intervals are used for models with a high frequency of oscillation, and are of increasing area with distance from the gun up to a maximum of 8 ft × 10 ft. A system of tubular steel frames which carry a reserve roll of paper is used to hold the paper

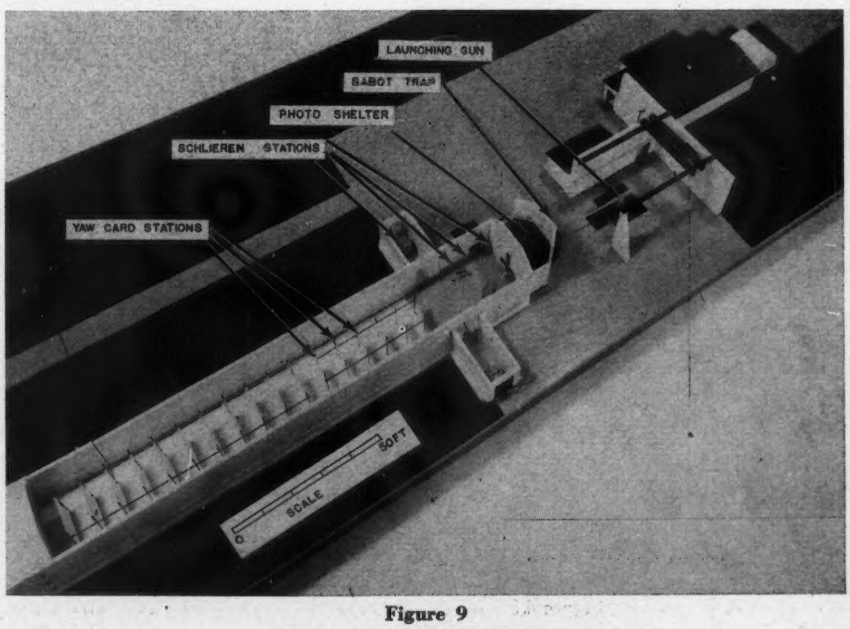


Figure 9
Model of aeroballistics range

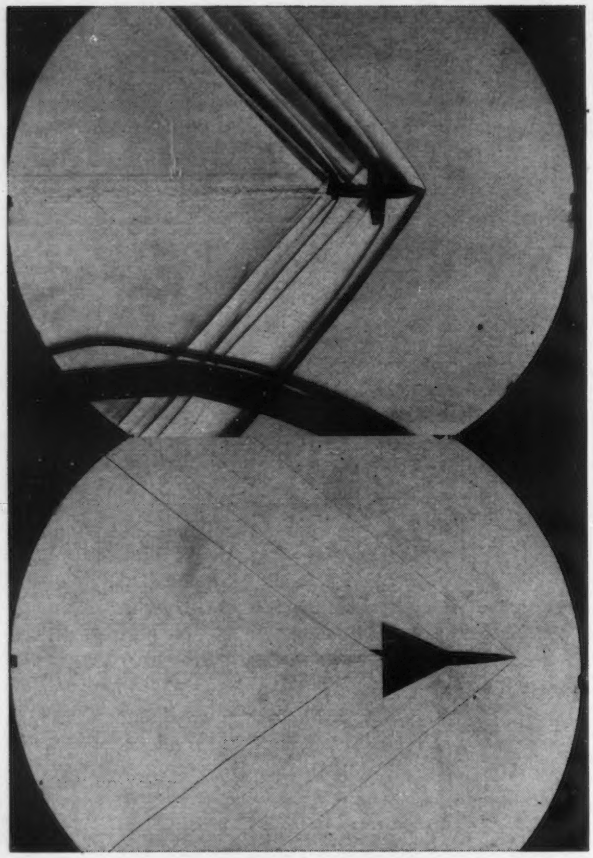


Figure 10
(upper) Bell X-1 schlieren, $M = 1.3$
(lower) NRC delta shadowgraph, $M = 1.6$

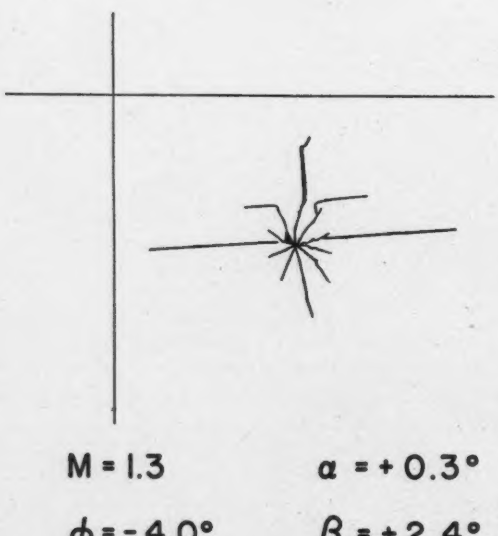


Figure 11
Typical yaw card cut

taut at the exact longitudinal location. By means of solenoid-actuated pins, reference marks for the horizontal and vertical datum lines can be made in the paper quickly and accurately.

A typical cut made in the yaw card paper by the Bell X-1 model is shown in Figure 11. Angle of attack α is determined by measuring the amount by which the distance between the nose point and the horizontal tailplane cut differs from the value for $\alpha = 0$. Sideslip angle β can be found by measuring the displacement of the fin cut to one side or other of the nose point. Roll angle ϕ is measured directly between the wing line and one of the reference lines. The accuracy with which attitude angles can be measured is from 0.05° to 0.1°, depending on the model configuration.

For flights where large angles of attack or yaw occur, this method for measuring α and β may be unsatisfactory if the cuts in the yaw card are poorly defined or if some of the reference points on the model are obscured. An alternative method which has been devised to cover such cases is the use of the "Flight Attitude Shadowgraph", shown in Figure 12. A model is mounted in a gimbal system so that it can be positioned in any combination of pitch, roll and yaw angles and these angles read directly from the protractors shown. Using a collimated light beam, a shadow of the model is cast on a screen and, by orienting the model until its shadow fits the yaw card cut, the attitude angles of the model in flight are determined. The accuracy with this apparatus is about $\pm 0.5°$.

Lateral motion of the centre of gravity, i.e. the trajectory of the model, is measured between the model

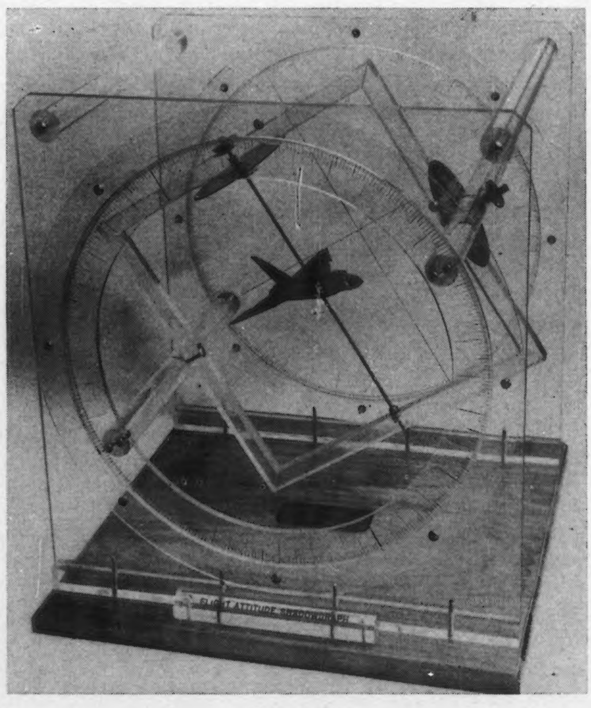


Figure 12
Flight attitude shadowgraph

cut and the horizontal and vertical reference lines, and can be determined to within 1/16th of an inch.

The effect of the yaw cards on the oscillations of the models is negligible for the small angle of attack range covered in most of the CARDE aeroplane experiments. For angles of attack above about 10°, the card interference affects C_{M_α} and a correction can be made for this. The effect of the yaw cards on the retardation of the model will be discussed later in the paper.

TEST RESULTS

Using the methods described in the preceding section, histories of α, β, ϕ, Y_{CG} and Z_{CG} are obtained as shown in Figure 13a, b and c for three typical rounds. These three records are all for the same configuration, at nominally the same Mach number, and a comparison of them shows the effect of CG position and inclination of the principal longitudinal axis of inertia. The round of Figure 13a has a forward CG position at 8.7% MAC and the record will be seen to consist of a small, rapidly-damped oscillation in pitch, while in yaw and roll there is a coupled Dutch roll oscillation of lower frequency but much larger amplitude. The points occur at the yaw card positions with intervals of 5 ft or 10 ft and at a sufficient frequency to give a good record of the shape of the β or ϕ curve. In Figure 13b the CG is at 19.2% MAC and the frequency of roll, pitch and yaw have all decreased while the damping has changed from being positive to slightly negative.

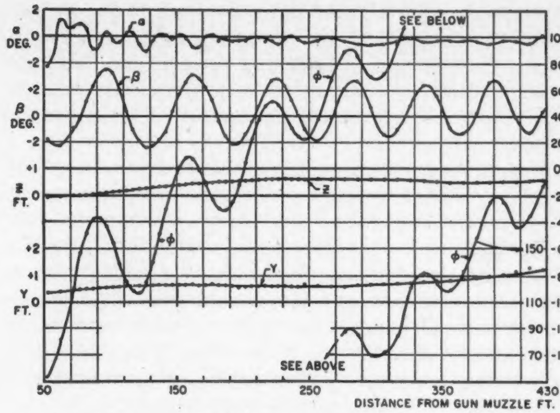
For these two rounds, the principal axis of inertia was inclined at about 2° below the fuselage datum. For the model of Figure 13c, the CG is still further aft at 22.9% MAC, but by ballasting with inserts as described earlier, the principal axis inclination ϵ has been reduced from 2° to 0 and the strong effect of this is obvious. The Dutch roll is of much smaller amplitude than before and is heavily damped. The oscillation in pitch, on the other hand, is of larger magnitude than for the previous rounds and shows no signs of cross-coupling from the roll or yaw. In this case, an initial displacement in pitch was achieved by mounting the model in the sabot at a positive angle of attack.

The fact that, by suitable ballasting and sabot design, either a pure pitching oscillation or a Dutch roll lateral oscillation with negligible cross-coupling can be selected is of considerable importance in the analysis of the results. It means that simple one or two degree of freedom solutions, which are amenable to manual methods of calculation, can be used to extract the necessary stability derivatives. In terms of time, this means that, firing models of a series at a rate of one per week, it is possible for two people to analyze the test results of one round before the next model is fired. This compares favourably with the amount of data reduction required for free flight tests using telemetry.

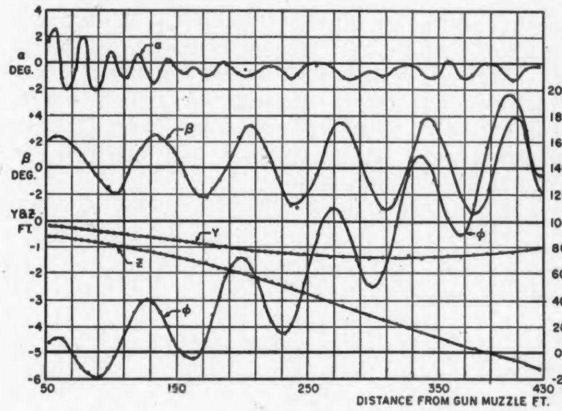
ANALYSIS

Lateral stability derivatives

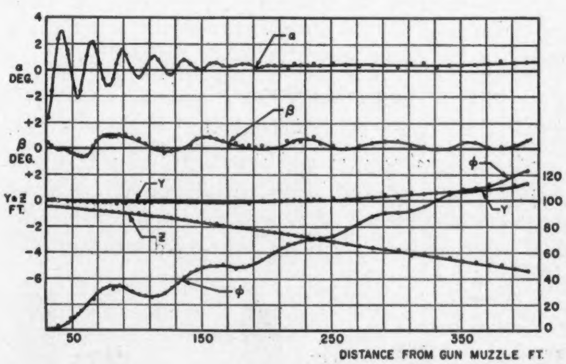
Various methods of analyzing this type of record have been considered. An analogue method of curve fitting has been applied to some of the test results[10] and has given derivative values in good agreement with those of other methods, although this approach does not appear well suited to solutions where three or more degrees of freedom are involved. Another method, which has been developed at Avro Aircraft for the analysis of their large scale ground-launched free-flight models, is an extension of Doetsch's time vector method[11] to lateral as well as longitudinal motions[12, 13]. With this method, each equation of motion is represented graphically by a polygon of vectors, one vector for each term in the equation. The length of each vector is a measure of the magnitude of the corresponding term, while its direction is governed by its phase relation to the other terms in



(a) Test record for forward CG, (8.7% MAC) $\epsilon = 2°$



(b) Test record for aft, CG, (19.2% MAC) $\epsilon = 2°$



(c) Test record for aft CG, (22.9% MAC) $\epsilon = 0°$

Figure 13

the equation. The required derivatives are found by adjusting the lengths of the vectors until the polygon closes, corresponding to balancing the equation. The use of this method to analyze full scale flight test records at the Cornell Aeronautical Laboratory is described in Reference 14.

The method which will be described here was developed by Mr. Templin at NAE and has proved very useful for the analysis of the Dutch roll motion. Referring again to the records of α, β and ϕ in Figure 13a and b, it has already been noted that the pitching motion is small enough that any roll-pitch cross-coupling can be neglected. The oscillation in roll is superimposed on a slow steady rate of roll, while the yawing motion is at the same frequency, with a slight shift in phase and approximately the same rate of damping.

Considering the records of the lateral co-ordinates of the model centre of gravity Y_{CG} and Z_{CG}, there is no apparent ripple at the Dutch roll frequency. Thus it may be assumed that the angle of yaw ψ is equal to $-\beta$, the sideslip angle. The implication of this assumption is that aerodynamic side forces are negligible and, therefore, that in the equations of motion the side force equation can be neglected, leaving only the two equations for yawing and rolling moments.

Making use of the above assumptions, these equations are as follows:

$$\frac{d^2\phi}{dt^2} - \frac{I_{xz}}{I_x}\frac{d^2\psi}{dt^2} = \frac{\frac{1}{2}\rho\, V^2\, Sb}{I_x}\left\{C_{l_\beta}\,\beta + C_{l_p}\frac{(pb)}{2V} + C_{l_r}\frac{(rb)}{2V}\right\} \quad (1)$$

$$\frac{d^2\psi}{dt^2} - \frac{I_{xz}}{I_z}\frac{d^2\phi}{dt^2} = \frac{\frac{1}{2}\rho\, V^2\, Sb}{I_z}\left\{C_{n_\beta}\,\beta + C_{n_p}\frac{(pb)}{2V} + C_{n_r}\frac{(rb)}{2V}\right\} \quad (2)$$

$$\text{where } \beta = -\psi,\ r = \dot{\psi} \text{ and } p = \dot{\phi}$$

On the basis of the character of the records, (and considering only the oscillatory part of the ϕ record) a solution of the form shown below is assumed:

$$\psi = \psi_o e^{-Kt} \sin \omega t \quad (3)$$

$$\phi = \phi_o e^{-Kt} \sin(\omega t + \theta) \quad (4)$$

ωt is set equal to zero and alternatively equal to $\pi/2$ in Eqs. (3) and (4) and in the corresponding equations for the first and second derivatives of ψ and ϕ. The two sets of values thus obtained are substituted into Eqs. (1) and (2), resulting in four simple algebraic equations. When the appropriate values of amplitude ratio ϕ_o/ψ_o, frequency ω, damping factor K and phase angle θ are substituted into these four algebraic equations, the only remaining unknowns are the six lateral stability derivatives C_{l_β}, C_{l_p}, C_{l_r}, C_{n_β}, C_{n_p} and C_{n_r}. With six unknowns in a set of four simultaneous equations, we are thus faced with a choice of assuming two of the derivatives and solving for the remaining four. In our work it was considered preferable to solve for C_{l_β}, C_{n_β}, and C_{l_p} as these three could most easily be verified from previous tests, and of the remaining three it was decided to assume C_{l_r} and C_{n_r} on the grounds of numerical size of the terms in which they occur.

Most of the test results so far obtained using this method have been for the CF-105 Arrow aircraft and, although quantitative results are classified, a bar graph comparison is given in Figure 14 of the derivative values from the NACA Langley wind tunnel tests, the ⅛th scale free flight tests and the CARDE tests. The CARDE values of C_{l_β}, C_{n_β} and C_{l_p} lie between those obtained from the other two methods. Typical comparisons of lateral derivatives from the analysis of the Bell X-1 and NRC delta models are given in Table 1 and in Figure 15a.

In using this type of analysis for a test program in conjunction with preliminary wind tunnel tests, it would probably be more advisable to use the wind tunnel values of C_{n_β} and C_{l_β} as the assumed values in the equations, and solve for the four rotary derivatives, as these are more difficult to evaluate from the wind tunnel.

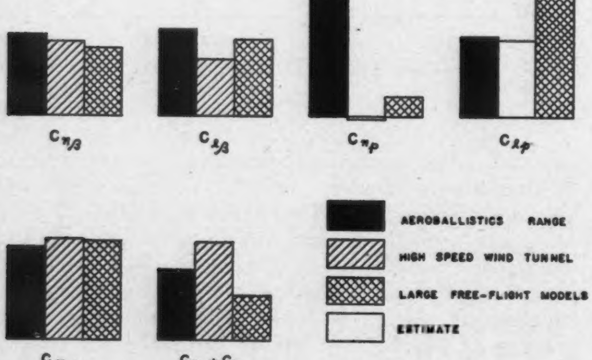


Figure 14
Comparison of test results for Avro CF-105 at $M = 1.5$

TABLE 1
COMPARISON OF AERODYNAMIC DATA FOR THE BELL X-1
(CG 22.3% MAC)

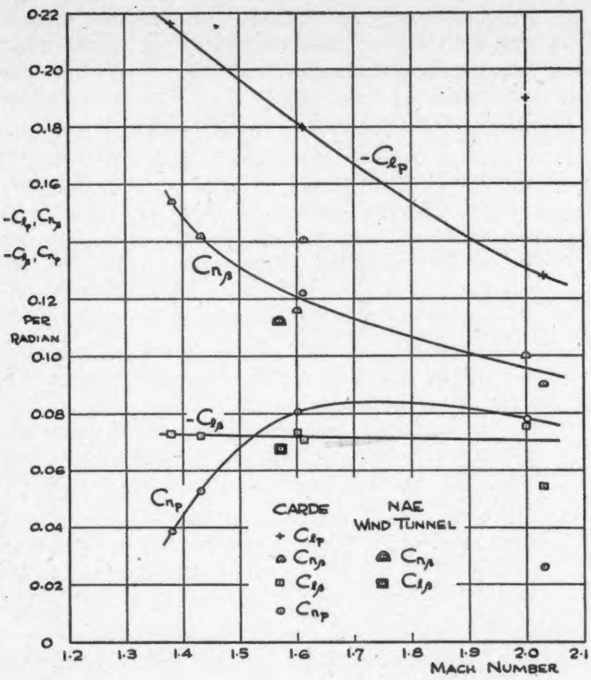
Derivative	M	CARDE Value	NACA Value
C_{M_α} per deg.	1.2	−0.038	−0.03
C_{n_β} per deg.	1.2	0.0069	0.004
C_{l_β} per deg.	1.2	−0.00275	−0.0018
C_{l_p} per rad.	1.2	−0.40	−0.41
C_{n_p} per rad.	1.2	0.313	–
C_{D_0}	1.2	0.14	0.144

Longitudinal stability derivatives

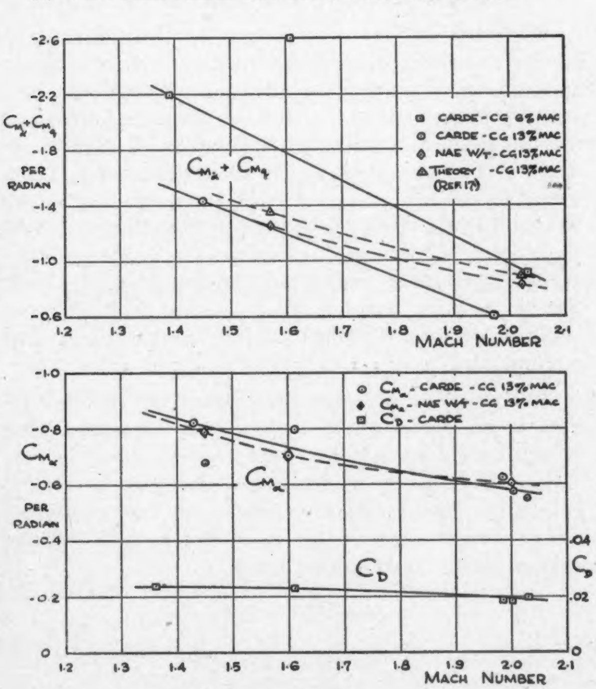
Analysis of the pitching oscillation to determine longitudinal stability derivatives is somewhat simpler than for the lateral case. Measurements of the frequency of the oscillation ω (or its wave-length λ) and the damping rate K are made and C_{M_α} can be found directly from the relation:

$$C_{M_\alpha} = \frac{-\,2I_y\omega^2}{\rho\, V^2\, S\bar{c}} = \frac{-\,2I_y}{\rho S\bar{c}}\left(\frac{2\pi}{\lambda}\right)^2 \quad (5)$$

A cross-plot of C_{M_α} vs CG position for several rounds at the same Mach number will give C_L as its slope and the aerocentre position as the intercept value of CG position for which $C_{M_\alpha} = 0$.



(a) NRC delta lateral derivatives (CG 13% MAC)



(b) NRC delta longitudinal derivatives (based on MAC)

Figure 15

The damping in pitch ($C_{M_{\dot\alpha}} + C_{M_q}$) is then obtained from the equation below:

$$C_{M_{\dot\alpha}} + C_{M_q} = \frac{2g\ I_y}{lV\bar{c}^2} C_{L_\alpha} - \frac{8\ I_y\ K}{\rho\ VS\bar{c}^2}$$

Some of the values so obtained for the Bell X-1 and the NRC delta are shown in Table 1 and Figure 15b. The good agreement of C_{M_α} with wind tunnel values will be noted.

Drag

One of the most important applications of the free flight technique is the measurement of aeroplane drag. The aeroballistics range method has the advantage over the ground-to-air technique in that the air in the range is at rest and is of constant density so that wind and altitude corrections are not necessary. There is also no correction for the effect of the gravity component on longitudinal acceleration. Furthermore, the data reduction with the light screen system used to measure velocity is very simple in comparison with that required for the Doppler radar apparatus. Another distinct advantage is that the models are so cheap to produce that a whole series of tests making small configuration changes to determine their effect on drag can be completed for the cost of one or two large fully-telemetered rounds.

As mentioned earlier, the error of the measuring equipment is of the order of 2% on drag. One difficulty with the use of yaw cards, however, is that part of this measured retardation is due to the effect of the yaw cards. Comparison of CARDE test results with those obtained using the same configuration (CF-105) at BRL, where only photographic methods of measurement are used, indicates an effect of the order of 4%. Although it might be possible to use a correction factor to compensate for this, the current plans will enable drag to be measured down-range of all the yaw cards to completely eliminate this error. Drag values obtained for the current models are given in Table 1 and Figure 15b. The comparison with the drag of the Bell X-1 is quite good.

FUTURE PLANS

The plans for further development of aeroplane testing in the aeroballistics range are closely related to the limitations of the present methods, and so the two can be discussed together.

Concerning manufacture and inspection methods, the two limitations of the present models are the extent of simulation of detail, because of the physical size of the models, and the limit in launch speed, because of structural difficulties. Under consideration at CARDE is a 14 inch gun which would permit double the scale of present models and simplify the manufacture and inspection problems. As launch speeds are increased, the inertia load of the model on its thrust pad increases rapidly so that for practical purposes the models described here would be limited to a Mach number of about 3 using the present gun. In the design stage at CARDE is a light gas gun which will permit this limit to be raised to Mach 10 for models of the present size.

A weakness of the range instrumentation as described here is the lack of any direct method of measuring lateral accelerations of the model. With such information, direct determination of force derivatives C_{L_α} and C_{Y_β} would be possible and greater accuracy could be obtained in the determination of drag in the absence of yaw cards. To meet this need, there is under development by a subcontractor a very small set which would

fit inside the model and transmit on two or three channels[15]. Early trials of the set have been encouraging. In addition to the application above, such an instrument could be used for such purposes as surface temperature measurements or the determination of hinge moments.

In future work, it is hoped to determine control effectiveness $C_{M\delta}$ by using a variety of elevator deflections on successive models and making use of the relation:

$C_{M\delta} = \frac{C_{M\alpha}}{\alpha_T/\delta}$ where α_T is the steady state trim value of angle of attack. One drawback of the range in comparison with either wind tunnels or ground-launched free flight models is that there is a limited range of trimmed lift coefficients for which the model will stay within the region covered by the range instrumentation. This results in a limitation in the amount of elevator deflection which can be used for the $C_{M\delta}$ determination above, and also means that the drag measurements have to be carried out very nearly at the zero-lift condition. This restriction can of course be relaxed to some extent by simply allowing the model to fly off to the side of the range before it has reached the end. As an example, if a steel delta model of 5 inch span flying at $M = 1.6$ could be allowed to diverge 6 ft laterally in the first 150 ft from the gun, a lift coefficient of 0.14 could be attained.

One field where much additional work can be done in these studies is in the extension of methods of analysis. Under study at present is an adaptation of the Fourier Transform method given in Reference 16 and, with the aid of digital computing equipment, it is hoped to apply other methods as well.

CONCLUSIONS

Tests carried out in the aeroballistics range using small delta and straight-winged aircraft models have established that:

(a) Manufacturing methods have been developed by which solid metal models can be manufactured at a rate of about 100 man-hours each to an average profile tolerance of ± 0.002 inches.

(b) Special care must be taken to check wing profiles and model contours prior to firing. Methods of measuring model moments and products of inertia have been developed.

(c) Models have been successfully launched into the range at speeds up to Mach 2.0 (Reynolds number about 3.8 million based on MAC) and, with present equipment, launch speeds of Mach 3.0 should be attainable.

(d) During the model's free flight down the range, its roll, pitch and yaw angles can be measured to within 0.1° and lateral centre of gravity position to the nearest sixteenth of an inch, using yaw card techniques. In addition, the model's velocity history can be determined, using a light screen system, to the nearest 0.3 ft/sec, while shock wave and flow visualization are obtained with schlieren systems.

(e) With suitable ballasting of the model and positioning of the model in the sabot, either a Dutch roll type of motion or a longitudinal pitching motion can be obtained independently, thus enabling the use of much simplified methods of analysis to determine the lateral or longitudinal stability derivatives.

(f) With the simple methods of analysis currently in use, reasonably close agreement can be achieved with stability derivatives determined in wind tunnels and with large scale ground-launched free flight models.

(g) The velocity-measuring system gives retardation values to an accuracy of 2%. A small drag increment due to yaw card interference has been noted (4%).

Although further development of the technique is needed to exploit all its possibilities, the results obtained so far have shown that the aeroballistics range can be a useful tool in determining the performance and lateral and longitudinal stability characteristics of high speed aircraft. The cheapness of the model construction and simplicity of data reduction make the method attractive in comparison with large-scale rocket-launched free flight models. However, it shares with such techniques the advantage over wind tunnels of giving high Reynolds number dynamic test data which are free from any possible errors due to tunnel wall or sting support corrections.

It is therefore felt that the type of test reported on here could prove useful not only to supplement the standard wind tunnel program for a final design of aircraft, but could be used at an earlier stage in design, before the "lines" had been frozen, so that configurational changes specifically to improve the dynamic characteristics could still be made.

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NOMINATIONS ARE INVITED

Each nomination should include

(a) The name and affiliation of the nominee,

(b) Confirmation that he is a resident of Canada,

(c) A citation of the particular achievement for which the nomination is being put forward, and

(d) The name of the nominator.

The nominee need not be a member of the C.A.I. and the achievement need not have taken place within the last year, though it should be recent.

Nominations should be in the hands of the Secretary not later than the 14th March, on which date they will be handed over to the McCurdy Award Selection Committee.

TOOLING APPROACH TO ARROW AIRCRAFT†

by E. B. Bragg*

Avro Aircraft Limited

THE Arrow is an extremely high performance aircraft necessitating a high degree of envelope accuracy and surface smoothness to achieve the required aerodynamic efficiency. For this reason, Avro management established a basic policy which governs the whole engineering and manufacturing approach to production. Irksome though this may have seemed at times to both Engineering and Production, it was felt that this policy was mandatory to effect the requirements of the Royal Canadian Air Force and the Department of Defence Production in producing the best possible product for the purpose intended.

An important part of this policy was that production tooling would be provided for an agreed production rate from the first aircraft. The reasons here are obvious, since such a highly complex piece of equipment requires a degree of tooling sufficient to ensure the product quality in itself, regardless of quantity, and also that a prototype program requiring extensive tooling readjustment for production would involve a prohibitive addition to the flow time.

In order to minimize design changes and possible production bottlenecks, close liaison was established with Production Engineering people situated in the Engineering Department. One of the first problems that had to be tackled was engineering release to production. An agreed breakdown and release schedule was essential so that planning, tooling and production could produce the right parts for the successive assembly stages in their proper sequence.

There is an element of risk in starting on an intensive tooling program concurrent with early product design effort. However, since the spectre of early obsolescence looms over all such products in such a rapidly developing sphere of science, it is essential to use all reasonable means to shorten flow times.

In order that a vehicle having maximum serviceability be provided, it was mandatory that from the first airplane a high degree of interchangeability should be maintained. Accordingly, Avro Production Engineering Department, in collaboration with the RCAF Design Engineering and Inspection Department, established the interchangeability of components and parts. An "Interchangeability Tooling Program" which would control the requisite points in their relative positions on the assembly fixtures was therefore mandatory, and, moreover,

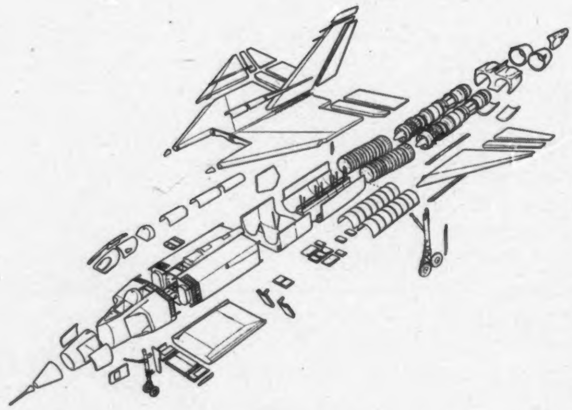


Figure 1
Component breakdown

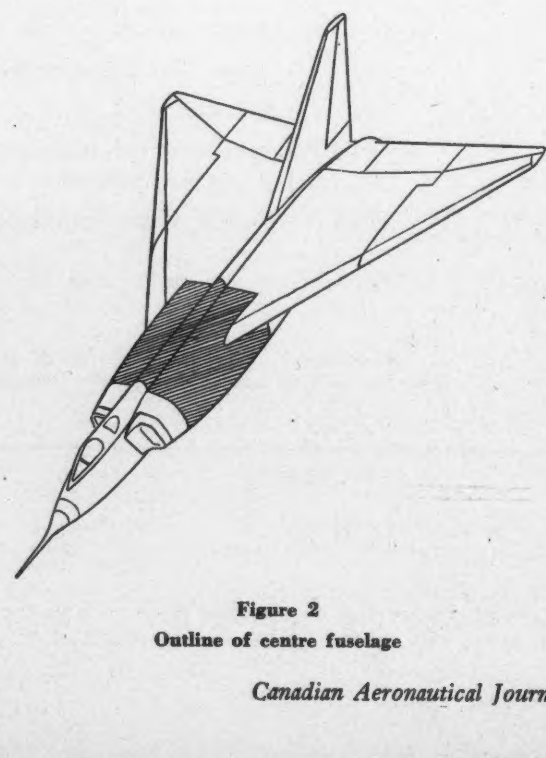


Figure 2
Outline of centre fuselage

†Paper read at the Annual General Meeting of the C.A.I. on the 27th May, 1958, in Toronto.

*Production Engineering Manager.

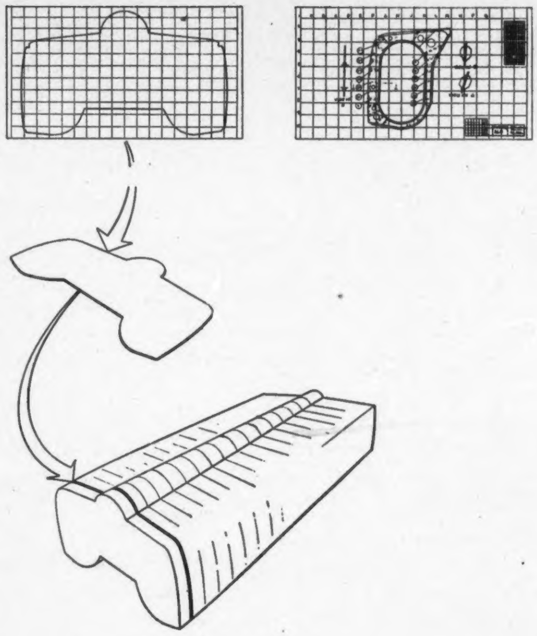


Figure 3
Engineering master lines

this program had to parallel that of the main assembly jigs to be effective. In addition, because of the contour control requirements on outside surfaces and the need for a basic shape to refer to for part and tool manufacture, a program of full scale master models was decided on.

COMPONENT BREAKDOWN

The component breakdown for the Arrow Aircraft for ease of assembly and for maximum serviceability is illustrated in Figure 1.

At the commencement of structural design, teams of planners and tool designers, under selected supervisors, were allocated to each major component. Their responsibilities were to initiate basic planning steps, to formulate the sequences of assembly, and to cooperate with the designers in every feasible manner in eliminating future problems of manufacture and assembly. As the design progressed through the detail stages, these personnel continued with the detail processing, and followed the component planning through its final assembly stages.

TYPICAL ASSEMBLY

At this stage, I propose to illustrate a section of the fuselage (Figure 2) through the various tooling phases.

Engineering master lines

As soon as the "envelope" of the aircraft was defined, full scale layouts of the master lines (Figure 3) were made on glass cloth. This then became the master lines glass cloth reproductions which, upon filling in the structural details, became assembly glass cloth drawings. When reproduced upon metal template material they provide a source of information from which the tooling master models for the component are made.

Utilizing glass cloth and the direct reproduction technique enables the printing of many reproductions each exactly the same, resulting in a startling reduction in layout time.

Master model

As we have shown, the master lines were reproduced on metal template material. The templates cut to outline shape were mounted on a rigid column at correct station positions. After ensuring correct fairing in the individual station templates, the spaces between them were filled with wire mesh and plastic (Figure 4). The resultant surface was splined smooth with the templates providing a solid surface reproduction of the component, as shown in Figure 5.

As the information became available, datum lines, skin trim lines, cut outs etc were added to the surface of the model as needed, to obtain the fullest usage from it. These models became the tooling masters controlling the envelopes of the components.

Skins and detail parts adjacent to the outside contour of the aircraft control its shape and therefore tooling for these parts is directly related to the model.

Stretch form blocks and routing baskets

From the master model plaster splashes, that is reverse female patterns, were made to transfer the shape into tools, such as stretch form blocks, drop hammer dies, and routing fixtures, as illustrated in Figure 6. This eliminated the need for individual patterns, since the splashes were taken from the appropriate area of the master model.

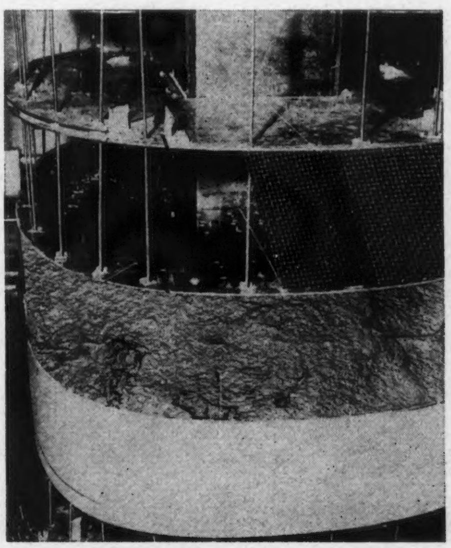


Figure 4
Construction of master model

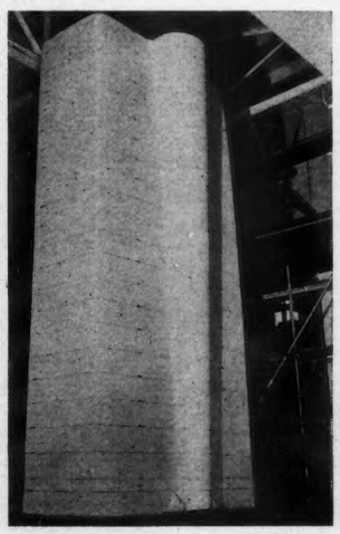


Figure 5
Master model

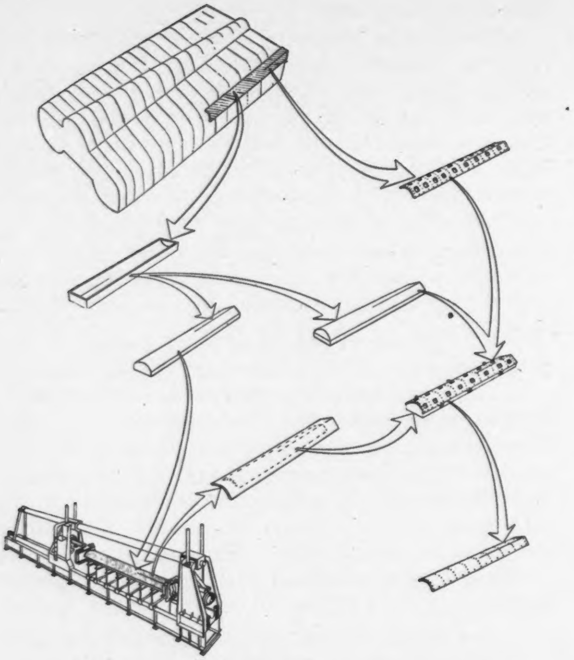


Figure 6
Stretch form blocks and routing baskets

Furthermore, the model established the trim areas for each skin panel in the correct relationship contour-wise ensuring proper fit.

Assembly glass cloth

Figure 7 shows a typical assembly glass cloth with its internal structural detail. Reproductions of this in whole or in parts were made directly on to sensitized aluminum

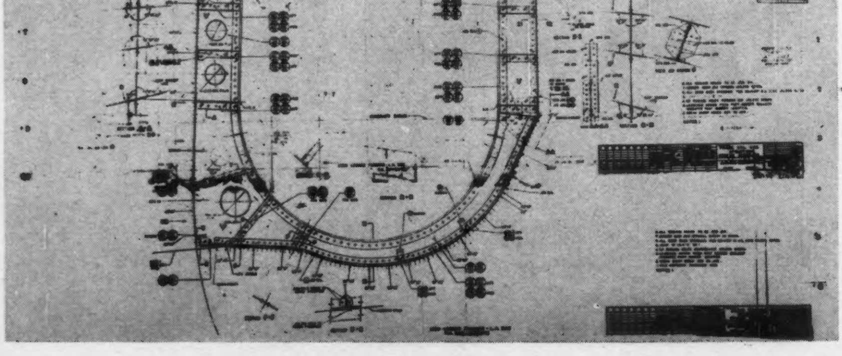


Figure 7
Assembly glass cloth

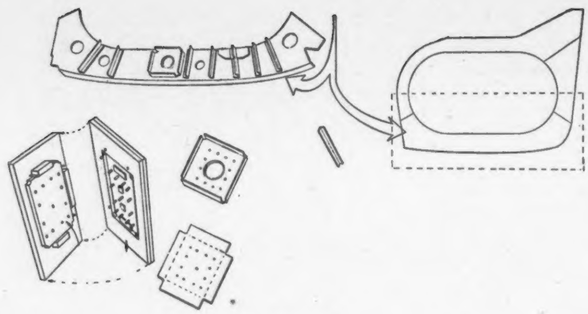


Figure 8
Tooling for sheet metal details

alloy template and tooling material to make tools for the details. (The contour has been proved out by placing a cut template into the master model to show proper fairing.)

Tooling for sheet metal details

The sheet metal detail parts were all made through the medium of direct reproduction of the assembly glass cloth on to the tooling material as shown in Figure 8. Where parts were flanged and required development, Production Engineering Loft Department added the developed flanges to glass cloth reproductions of the assembly glass cloth. Figure 9 shows the assembly of these three former sections ready for riveting.

TOOLING FOR ASSEMBLIES

The policy maintained in respect to assembly tooling was one of economy commensurate with adequate control of interchangeability points, major component pick-up points, and skin contour. Sub-assembly jigs were not ordered wherever the work could be achieved by either self location, that is pre-drilled and matched holes, or by inclusion in the next assembly stage. In addition, the assembly jigs which were provided, though of production type, were equipped with essential locators only, the intention being to add additional facilities on the basis of production requirements.

Sub-assembly jig

In Figure 10 we have the smallest type of assembly breakdown as shown in the previous Figures — the half section fuselage bulkhead. This was composed of three minor sub-assemblies which did not require assembly jigs. However, the positioning of the three sub-assemblies relative to outside contour was critical, necessitating the sub-assembly jig shown at the top right in Figure 11.

Wherever practical this type of bulkhead assembly is completed in a vertical assembly jig,

as shown here, to provide for easy accessibility and to conserve floor space. A further saving was achieved by making the jig frame a standard size and having the locators for each bulkhead mounted on individual boards. These boards are positioned as required to complete the parts on the standard frames and when not in use are stored vertically in racks adjacent to the assembly area.

Major assembly jig

The next stage of assembly comprised the attachment of the half centre fuselage. Bulkhead members were assembled to the engine air intake duct and partial skinning of the external surface completed. For this stage a major assembly jig of the type illustrated in the lower part of Figure 10 and in Figure 12 was provided.

Complete assembly

Completion of the assembly of the centre fuselage

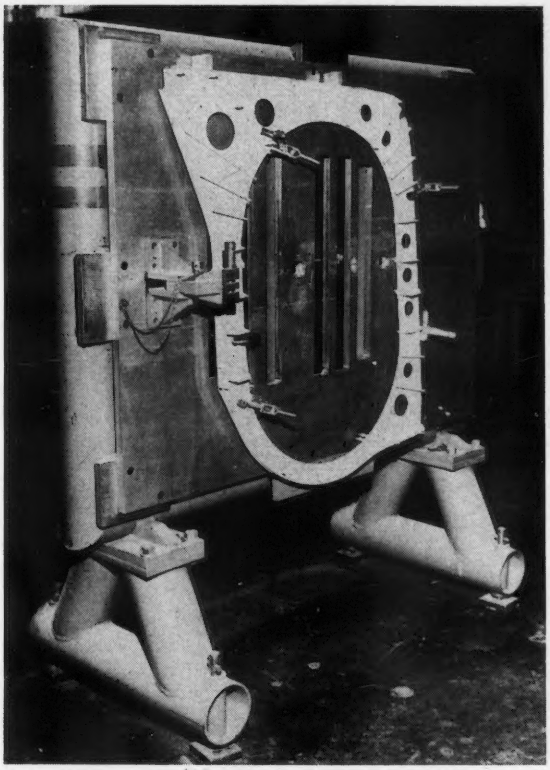


Figure 11
Half section fuselage bulkhead assembly jig

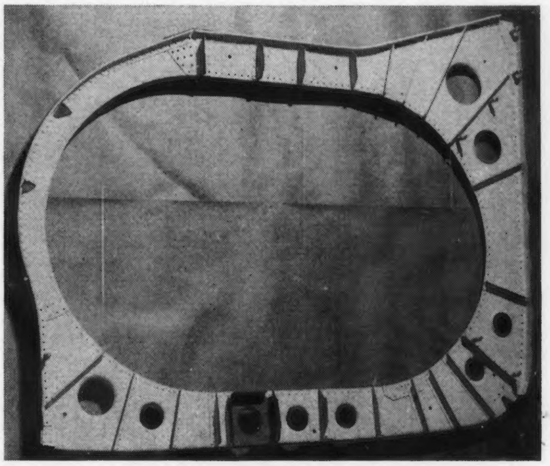


Figure 9
Former sections ready for riveting

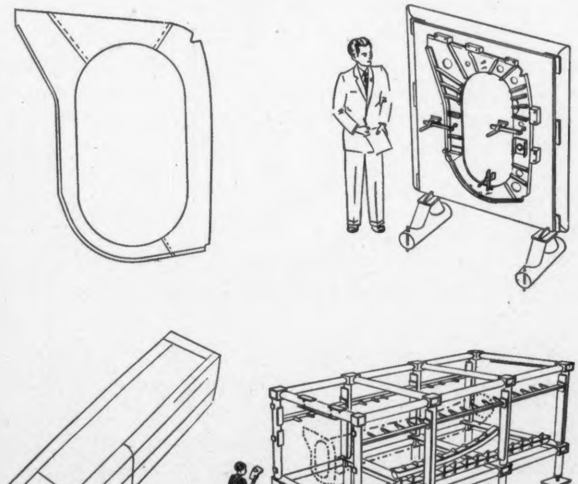


Figure 10
Tooling for assemblies

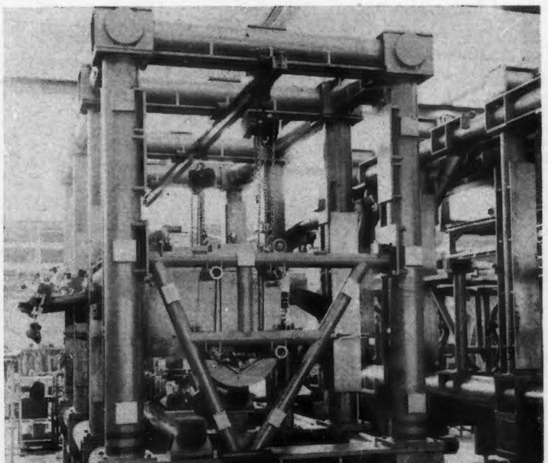


Figure 12
Half section fuselage jig

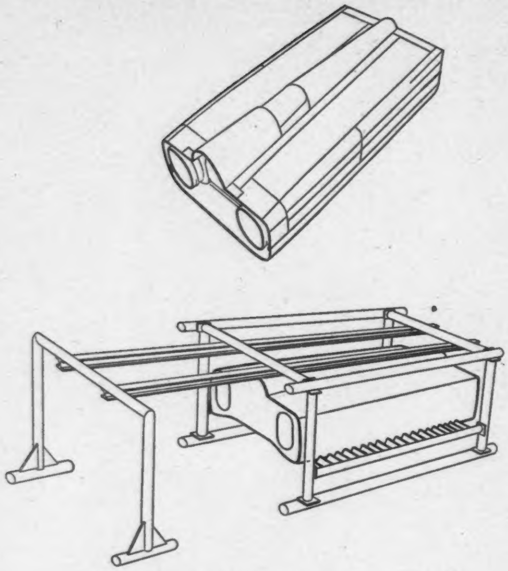


Figure 13
Centre fuselage assembly jig

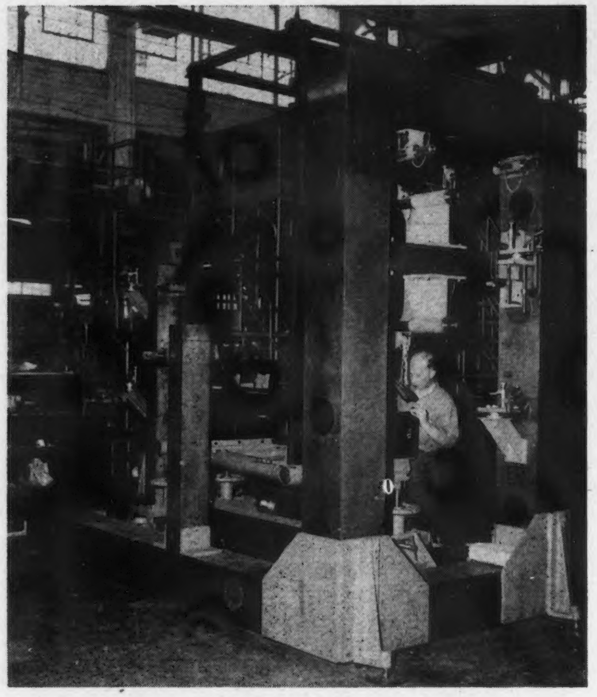


Figure 15
Jig using standard sections

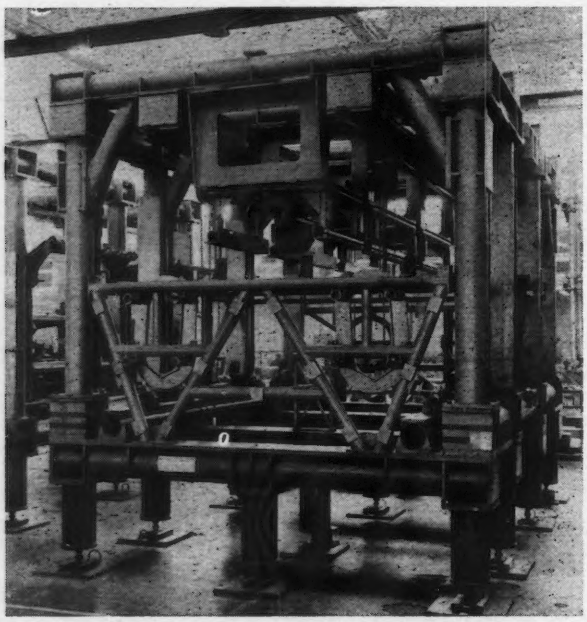


Figure 14
Centre fuselage assembly jig

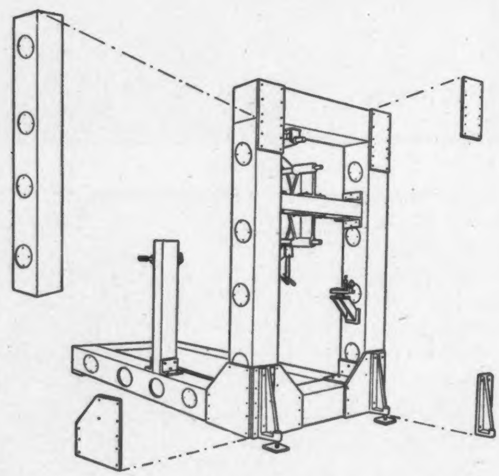


Figure 16
Jig using standard sections

half sections with assurance of correct final marry up with adjacent components and to maintain envelope accuracy required a component assembly jig as illustrated in Figures 13 and 14. This jig was positioned between each of the half section jigs so that completed half sections could be moved into the final stage with a minimum of handling.

DEVELOPMENT OF THE USE OF STANDARD SECTIONS

At this time I should like to point out some of the ideas which have been adopted during the tooling program towards standardization of jig design, particularly with respect to large assembly jigs such as that illustrated.

Wherever practical the large jigs were designed so that they could be easily fabricated as a number of smaller units. These units could be assembled complete in the conventional tool room manner on the surface tables. Then with the aid of optical setting equipment and jig references the individual units were assembled to form the complete assembly jig.

During the early part of our tooling program these units were fabricated from standard, commercially avail-

able, steel sections of pipe, angle, channels and I-beams.

In order to effect economies in tool design and tool build structure-wise, a number of standards were prepared comprising a series of standard cast iron box beams, joint plates and legs. These were obtained, stress relieved and pre-machined to size and are maintained as stock items.

The jig (of another component) shown in Figures 15 and 16 should be compared with that in Figure 14. The cleanness of the structure and ease of tool build made possible by the machined cast iron sections is very apparent. In the tool design stage the draftsman does not separately detail each of these standard items (Figure 17), thus reducing drafting time by approximately 10 to 15%.

Similarly the tool making time for fabricating the large sections as they are required is entirely eliminated which, together with the greater ease of build achieved, results in a saving in overall tool build time of approximately 20 to 30%.

As well as these immediate savings on the Arrow Tooling Program, long term saving will be achieved in that the assembly jigs using standard sections can be readily broken down and the sections released for further use immediately without any additional work being performed upon them.

Some indication of the extent to which this standardization has been pursued can be gained by the number of such major assembly jig items now standardized. At the commencement of the program there were approximately 3 items; there are now 45. In addition, many of our sheet metal and machine tools and parts are covered by an extensive standards system so that in many cases tool design is not required at all. Planners make note of an appropriate code number on the tool masters.

INTERCHANGEABILITY CONTROL BY MEANS OF JIG REFERENCES

To return to the Arrow centre fuselage, I have attempted, briefly, to show you the manner in which control of the "envelope shape" of the component is effected by means of the master model and assembly glass cloth through the various tooling stages. It is, however, highly essential that components built in their respective assembly jigs will go together accurately when "married up".

This requirement, essential to assembly line performance, is of even greater importance from the point of view of servicing the airplane outside the plant facilities on some RCAF station.

Figure 18 illustrates the manner in which the interchangeability of the centre fuselage was controlled by means of jig references. In effect, jig references are master components or essentially very accurate replicas of those attachment points of the component that must be controlled. As shown here, this amounted to control of the forward joint at wing to centre fuselage, centre fuselage to duct bay, and a number of points at the forward fuselage end. The jig references for the centre fuselage are shown in position in the component assembly jig in Figure 19.

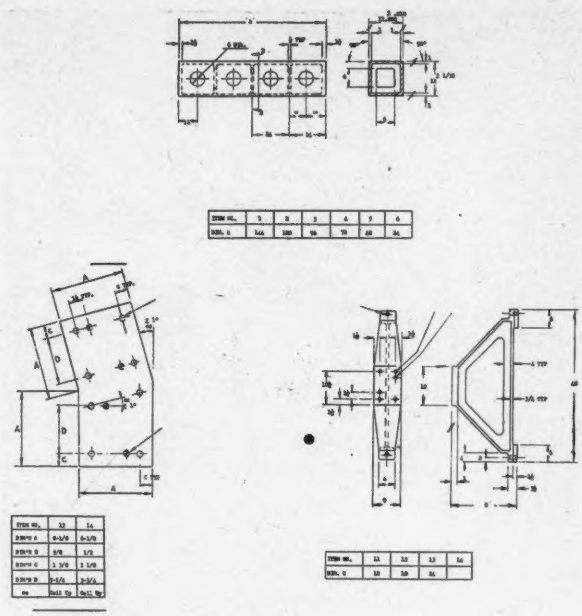


Figure 17
Standard sections and fittings

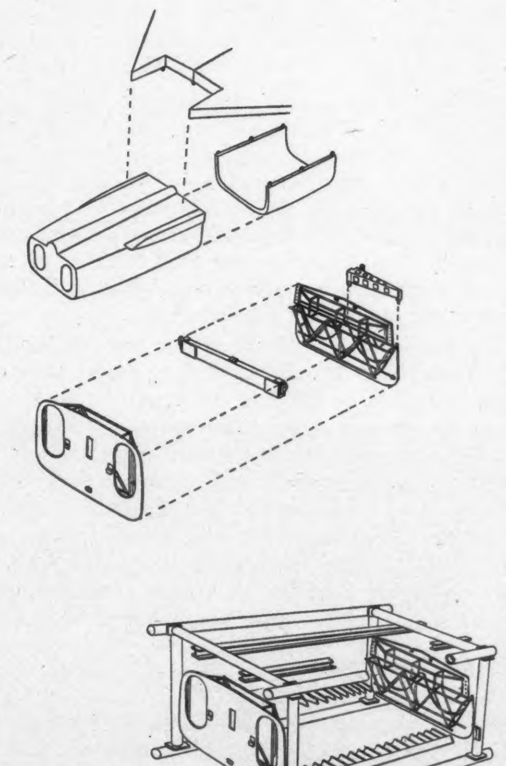


Figure 18
Jig reference for centre fuselage

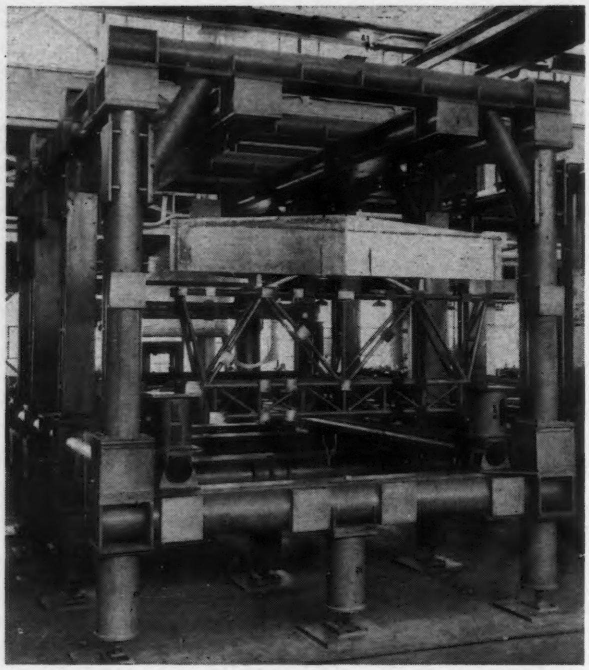


Figure 19
Jig reference in centre fuselage jig

The jig references are used for three main purposes:

(a) To finally position accurately the jig locators, which in turn locate the interchangeability points on the component.

(b) For periodic inspection of these jigs.

(c) For setting up duplicate jigs when required.

For simple joints where the adjacent component joints are identical, one reference suffices. In more complex joints separate jig references are provided for each component. These are first matched together to make sure the required fit is available and then each is used in its respective component assembly jig.

The references are designed for ease of handling, while maintaining sufficient rigidity to ensure their continuing accuracy. In building this type of tool, the important dimensional information is obtained from engineering basic geometry drawings, and contours are established from the master lines glass cloth or the master model. As the accuracy of tool build is increased through greater usage of pre-machined standard sections, unitized construction, and through the application of more accurate jig setting methods, i.e. optical tooling, we feel the need for jig references will be drastically reduced.

MACHINED FITTINGS

Throughout the foregoing we have not mentioned tooling for machine shop type parts. However, in the case of the Arrow centre fuselage the numbers of machine shop parts were at a minimum and could be divided into three classifications:

(1) The first item in the top left hand corner of Figure 20, being the simplest type, is produced without tooling.

(2) The second item shown in Figure 20 is typical of a part which can be machined almost completely without tools.

(3) The part in the lower left hand corner of Figure 20 is more complex in that it is produced from bar stock and requires provision of more extensive tooling to ensure the required accuracy. This part and its tooling is also shown in Figure 21. In view of the quantities of aircraft to be produced, it was mandatory that tooling of this type should be reduced to an absolute minimum.

FINAL MARRY UP DOLLY

The large size and nature of the components for the Arrow aircraft necessitate provision of an assembly fixture in which all major components, including the centre fuselage, are married up to form the complete aircraft

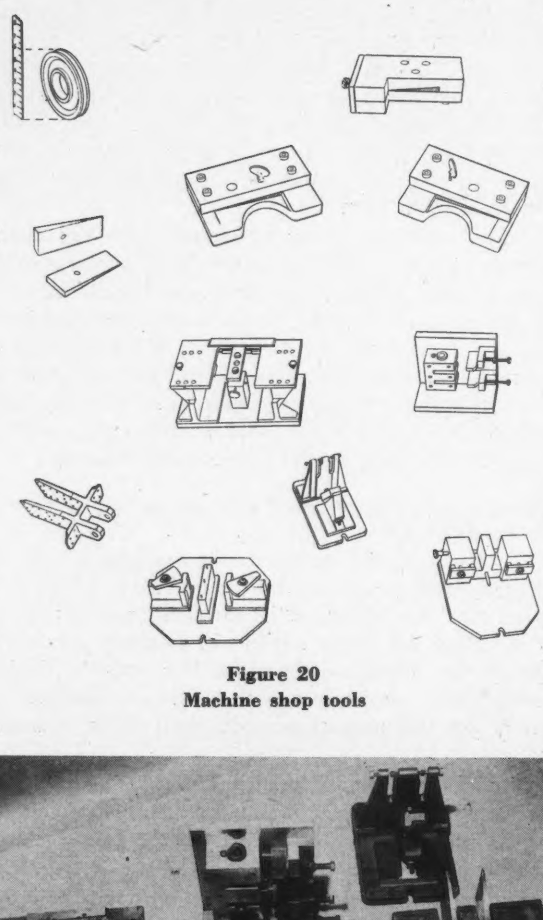


Figure 20
Machine shop tools

Figure 21
Machine shop tools

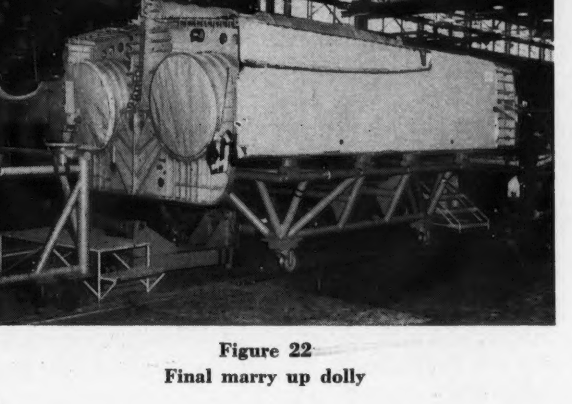


Figure 22
Final marry up dolly

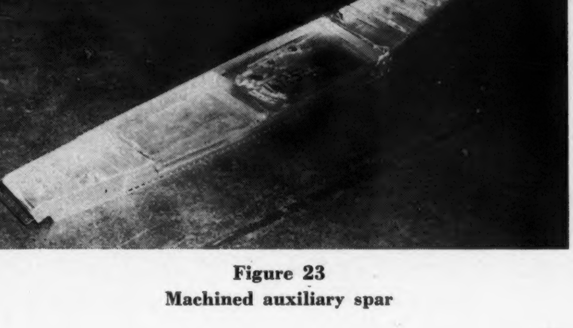


Figure 23
Machined auxiliary spar

structure, a procedure which was unnecessary on the CF-100. Figure 22 illustrates the completed centre fuselage on its assembly dolly prior to assembly with the wing and rear fuselage sections.

THE WING

No talk on the subject of tooling for the Arrow aircraft would be complete without some mention of the wing. This component has probably provided most of the problems and more interesting highlights than any other during the Arrow Tooling Program.

The inner portion of the wing is almost completely composed of integrally machined items. Ribs, spars and skins have all been machined from solid aluminum plate and hand forgings. Our Mr. H. F. Young covered most aspects of this feature during his talk on "The Machining Approach to Aircraft Production"[1] given at the Annual General Meeting of the C.A.I. in Montreal, so I do not propose to spend too much time on this at present.

Briefly, on the Arrow aircraft we have approximately 300 complex integrally machined parts which require extensive machining. The majority require profile milling operations, necessitating provision of special profile milling machines in addition to the families of templates and work holders required for each of the parts.

An auxiliary spar used in the wing is shown in Figure 23 and it is typical of the complexity of machining involved.

The main undercarriage pivot fitting is shown in Figure 24; in addition to its function as an undercarriage pivot, this fitting is also a main joint within the wing.

Figure 25 shows a fully machined wing skin, typical of the twelve fully machined skins used on the Arrow wing. The aluminum billets for these skins are 18′ long and 5′6″ wide and weigh approximately 2,300 lb at commencement of machining. The finished skin weighs approximately 250 lb. The machining of these items is accomplished on a large Kearney and Trecker skin mill. Tooling for each of the skins consisted of a large 6′ × 20′ aluminum alloy vacuum chuck (or work plate) to hold the work flat on the machine table, a rise and fall template made from three accurately ground cast iron billets and representing the complete inner surface of the skin

Figure 24
Main undercarriage pivot fitting

Figure 25
Machined wing skin

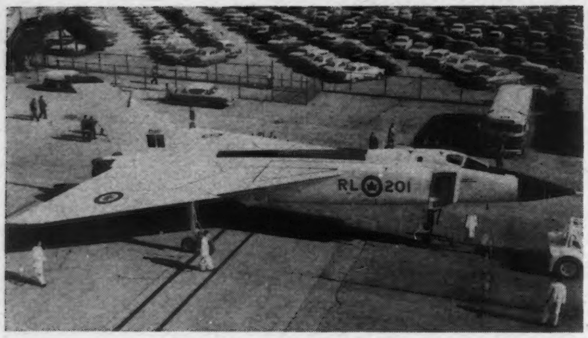


Figure 26
The Avro Arrow

to within an overall accuracy of ±0.002", and a series of full size profile templates for the plan form contours.

Concurrently with the heavy machining problems, the inner wing posed an additional problem in that it forms the main fuel carrying member, with extensive sealing requirements at all structural joints.

During the assembly stages, each tank cell is subjected to stringent pressure and leakage tests, while still in the jigs. Gaps greater than 0.005" between the mating surfaces of skins, ribs and spars cannot be tolerated. All attachment holes require reaming to tolerances of ±0.002".

CONCLUSION

Although I have only briefly touched on some of the problems in the approach we have made on this modern airframe, I hope that I have been able to convey to you some idea of the magnitude of the tasks involved, which, incidentally, entailed the planning and tooling for some 5,500 machine shop parts, approximately 32,500 sheet metal parts and 1,800 assemblies. This is very nearly three times the numbers encountered on the CF-100 program. In spite of headaches, grey hairs and ulcers, I think that the end result (Figure 26) has proven the efforts to be worthwhile.

REFERENCE

(1) Young, H. F. – *Machining Approach to Aircraft Production*, Canadian Aeronautical Journal, Vol. 2, No. 7, September, 1956.

TECHNICAL FORUM

Symposium on Rocket Research of the Upper Atmosphere

This was organized by the Associate Committee on Geodesy and Geophysics of the National Research Council and was held on the 30th October, 1958, in Ottawa.

The purpose of this symposium was to acquaint various researchers with experimental techniques in upper atmosphere research in which rockets are used as equipment carrying vehicles. Although not directly concerned with rocket technology, it is stimulating to aeronautical engineers to find such a large group of scientists in Canada interested in the use of rockets. It seems, therefore, useful to indicate briefly the topics discussed in the 11 papers presented at the symposium.

C. O. Hines (D.R.B.) — *The D.R.T.E. Study-conference*

Recently a study-conference was organized at the Defence Research Telecommunications Establishment. The first purpose of this conference was to educate the participants and the second purpose was to prepare a preliminary proposal for a Canadian rocket research program. It is felt that after the I.G.Y. much interesting work could be carried out at Fort Churchill where I.G.Y. firings are now taking place. Two Canadian rockets are proposed: (1) a rocket with 150 lb payload and maximum altitude of 150 km and (2) a rocket with 30-40 lb payload and 100 km altitude. Apparently much attention was paid at this conference to organizational problems. It was recommended that one man should be responsible for the experiment from design till completion. This senior man must understand all associated equipment. The estimated costs of rocket research are $50,000 per research worker. This figure is very approximate and although it may seem rather high compared with many scientific activities, there are certainly research projects costing more than that. So far no definite proposals have been submitted.

R. F. Chinneck (D.R.B.) — *The CARDE I.G.Y. Rockets*

CARDE already has experience in upper atmosphere research, namely measurements carried out with a spectrometer mounted in a wing tip pod on the Avro C-100. Also equipment has been carried by balloons in stabilized gondolas up to 35 km.

CARDE has designed and built two instrumented nose cones to be carried by the I.G.Y. Nike-Cajun rocket combination. The firings were scheduled for the 5th and 10th November, 1958. Some design features of these nose cones were described. Telemetering of

measurements and position is carried out through the same system. Three receiving stations are used to determine the position of the rocket in space. The nose cone is not thrown off to allow measurements to be taken, but moves forward only.

W. Keikkila (D.R.B.) — *Electron Density Experiments*

An accurate knowledge of electron density distribution in the D, E and F layers is important in radio wave propagation. Some measurements have been performed with American and Russian rockets. The measurements are based on transmitting signals in the range of 4-10 Mc which are affected by the ionosphere, and signals of much higher frequency which are unaffected by the ionosphere. The difference in velocity of propagation results in a phase shift at the receiving station and from this the refractive profile can be constructed. A critical region exists at about 110 km altitude. There are regular (day and night) and irregular (related to the appearance of sun spots) changes in the upper atmosphere electron density.

D. C. Rose (N.R.C.) — *Cosmic Ray Experiments*

Only a very small fraction of cosmic ray energy can be measured on the earth's surface and it is here that upper atmosphere studies are extremely valuable. Some recently published data obtained with the Explorer satellite indicate that surprises are in store. In the region where the Explorer measured high radiation no variations with time seemed to occur, suggesting a band of cosmic particles scattered from the earth's atmosphere and now in stable orbit around the earth.

H. I. Schiff (McGill) —
Chemical Reagents as Atmospheric Probes

Upper atmosphere and space appeared to be an interesting laboratory for the chemist. For instance, there are 50 possible reactions between H and O, if all excited stages are considered. Many of these cannot be realized in a laboratory since various species would disappear immediately in the wall of a bottle or be absorbed by surrounding air.

By ejecting a chemical component in the upper atmosphere and observing the reaction, conclusions can be drawn about the atmosphere composition. For instance, in the American project Firefly NO was ejected at 160 km height giving the reaction $NO + O \rightarrow NO_2 + h\nu$. By observing the decrease in intensity of the resulting cloud, conclusions could be drawn about the O-concentration.

Dr. Schiff suggested the use of the atmosphere as a series of chemical shelves, in which various experiments can be carried out once the vertical composition of the atmosphere is known.

A. G. McNamara (N.R.C.) — *Artificial Meteors*

In studying meteors a lack of aerodynamic data is apparent in the high altitude range and speeds from 7 to 70 km/sec. Dr. McNamara indicated briefly possible means of obtaining hypervelocity data. Artificial satellites of which the area, mass and height as a function of time are known would provide useful calibration results for meteors when entering the atmosphere.

A. D. Misener (Un.West.Ont.) —
Supporting Laboratory Experiments

Dr. Misener's main topic was the supporting role of a university if a Canadian rocket research program were undertaken. He expressed the desire of universities to receive problems of a fundamental nature without too much outside pressure.

R. D. Russell (Un.Br.Col.) — *Mass Spectrometry*

Various types of spectrometers and their adaption to rocket research were discussed.

S. R. Penstone (D.R.B.) — *Telemetry and Recovery*

A review was given of systems for telemetering data back to earth. The FM – FM systems appeared to be quite adequate for high altitude research, with typical accuracies quoted at 1-2%. Sometimes recovery is necessary, for instance for the purpose of examining animals carried in rockets or for photographic studies. In the first case a parachute will be necessary while in the second case armoured casing may be sufficient.

J. L. Locke (Dom.Obs.) — *Astronautical Experiments*

In studying the spectrum of radiation from the sun, the astronomer is greatly handicapped by the large amount of absorption in the earth's atmosphere. Dr. Locke described American experiments with sun spectrographs carried by rockets, particularly when solar flares took place. A spectrograph with self-directing mechanism allows the study of radiation as a function of time and measurements across the sun diameter.

W. Johnson (D.R.B.) —
Physiological Experiments on Weightlessness

Dr. Johnson showed a film of the behaviour of cats in normal condition and cats with the nerves of their balance organ in the ears cut. Their behaviour was studied on the ground and in an aircraft travelling along a parabolic arc. In the latter case short periods of zero acceleration were attained. From the wild behaviour of "normal" cats as compared with "operated" cats under weightless condition, it was concluded that test animals to be carried on rockets should have their balance system disengaged.

It is quite apparent from these summaries that a rocket research program in Canada would meet with enthusiastic response from workers in many fields.

Ottawa — J. A. van der Bliek

C.A.I. LOG

SECRETARY'S LETTER

"Subscribing members do not just contribute money, though that helps, they also commit themselves to the objects of the Union and become, more or less, active agents wherever they may be."

These were the words of our Patron, His Royal Highness the Prince Philip, when he addressed the English-Speaking Union in Ottawa at the end of October. They are as true of the Institute as of the Union or any other membership society. Membership of the Institute is a commitment and every member has some responsibility to the promotion of its objects and the development of its activities.

I notice that Mr. E. C. Wells, President of the I.A.S., will contribute an editorial to *Aero/Space Engineering* in December, in which he will discuss the responsibilities of I.A.S. membership. I am sure that it will be worth reading and it is my misfortune that I cannot refer to it now and borrow some of his ideas. However, it is significant that from time to time the members of almost every organization of any size have to be reminded that without them the organization would not exist and without their efforts it could not work.

BRANCH AND SECTION COMMITTEES

In saying this I should like to draw attention to those members who are "active agents" in every sense, namely the members of the Executive and other Committees of the Institute's Branches and Sections. Month after month the pages of the C.A.I. Log bear witness that the Branches are very much alive, every one of them. I can assure you that their programmes don't just happen; they represent a good deal of thinking and planning and letter writing and reporting by people who are busy men anyway. The Sections too are beginning to contribute to the work of the Institute, though to date their meetings have usually taken the form of sessions included in the programmes of Institute meetings and have not been reported separately; they have demanded considerable effort from the Section Officers nevertheless.

We should all be duly grateful and the least the rest of us can do is to attend meetings whenever we can. Let them see that their labours are appreciated.

THE JOURNAL

This Journal provides another instance of service by our members for our members. With our small staff the production of the Journal cannot compare with the production of commercial publications; it must depend on Branch Secretaries who report Branch activities, members who report on sessions at Institute meetings, members who review books and, of course, members who submit technical articles and notes. The members of the Publications Committee and Editorial Board are frequently called upon for help and advice. All these "active agents" produce the Journal, though I believe that it is generally regarded as a service to members that emanates entirely (and miraculously) from Headquarters.

However, we need more help, particularly in gathering incidental material, such as pictures for the frontispiece and short technical notes of general interest. There is nothing very subtle about the frontispiece; the idea is that each issue of the Canadian Aeronautical Journal should start with a picture of something Canadian and aeronautical – and preferably mildly topical. Every plant and laboratory in the country must have quantities of interesting photographs which would be suitable but, almost every month, we have to scratch to find something. It would be a great help if members far and wide, in the course of their daily rounds, would remember the responsibilities of their membership and, whenever they see something that might be appropriate to their Journal, send it along. If any photograph needs a short note of explanation, perhaps with one or two supporting photographs, so much the better; such material is always welcome.

SEASONS GREETINGS

We at Headquarters wish you all a Happy Christmas and a Golden 1959.

BRANCHES

NEWS

Winnipeg

Reported by G. G. Trice

September Meeting

The Winnipeg Branch opened its 1958-59 season with a Dinner Meeting at the Winnipeg Flying Club on the 30th September, 1958. Present were 64 members, 22 guests and members of the local press. Fifteen of the guests indicated their interest in becoming members of the Institute.

Mr. E. L. Bunnell, Chairman, opened the meeting after an excellent dinner. He introduced the new Branch Committee Chairmen and apologized for the absence of three, due to business commitments. The CAI blazer badge was shown to those attending the meeting and they were informed that further details could be obtained from the Branch Secretary. Mr. Bunnell then introduced the speaker, Mr. C. Brereton, Regional Superintendent of Air Traffic Control for the Winnipeg Region.

Mr. Brereton has seen and been directly concerned with the development of air traffic control in Canada from 1937, as a radio operator and agent for Canadian Airways at Sioux Lookout, to the present day, when he is probing the future requirements of the jet transport age. The speaker introduced his talk on the Air Traffic Control Service by dividing the responsibility of the Service into four divisions and outlining the first two – the safe operation of aircraft in designated control areas and to expedite the flow of this traffic. These were illustrated by a US Navy film of the flight planning and flight of a DC-3 in a highly concentrated air traffic area with the consequent high delay rate of transmission of clearances.

Mr. Brereton explained briefly traffic limitations of VFR conditions intermingled with IFR conditions and explained the existing air traffic control centre system employed in Canada and the adjoining United States areas. He then went on to discuss the problems of the present method in relation to jet aircraft operations and saturated air routes. He stated that the Canadian Government established the block airspace system in 1956, which the USA is now introducing after three disasters resulting from a mixture of IFR and VFR traffic. Canadian Air Traffic Control is finding that the block airspace system has its saturation limitations and the speaker said that they were once more ahead of the USA by developing the system further with the introduction of Raytheon L Band medium range radar units, which will enable aircraft to be vectored around each other rather than provide 10 minute time separation. The next stage, Mr. Brereton said, will be the introduction of automatic computers which will accurately and rapidly calculate conflicting points, time to begin descent and rate of descent to enable jet aircraft etc to arrive at the terminal at exactly the right time for a no-delay approach.

Mr. H. R. Eiler thanked Mr. Brereton for his very fine talk and film.

The meeting was followed by a very well conducted tour of Winnipeg Air Traffic Control departments, including the Tower, Approach Control, Air Traffic Centre and the Air Traffic Control School.

Reported by G. Milner

October Meeting

This meeting was held in the Training Centre at Bristol Aircraft (Western) Ltd. on October 28th, 1958. Mr. E. L. Bunnell, Chairman, expressed some disappointment at the small attendance (27 members present) and hoped that more interest could be promoted in future. He then introduced the speaker, Wing Commander C. J. Evans, Chief Technical Staff Officer at RCAF Stn. Winnipeg.

W/C Evans, who joined the RCAF in 1940, was an operational pilot during the last war and graduated in Aeronautical Engineering in 1949. Recently appointed to his present post, he was previously Associate Professor of Fluid Dynamics at the Royal Military College and was responsible for the design and installation of a low speed wind tunnel there.

W/C Evans introduced his talk on wind tunnels with a humourous reference to the presence of the press at the September dinner meeting and subsequent notoriety given to the RCAF week-end flying and hoped that nothing could be construed out of his talk.

The speaker then covered the early history of the use of wind tunnels and various uses to which they have been put during the past 87 years. The epidiascope was used to illustrate this and later parts of the talk.

W/C Evans described the low speed wind tunnel at RMC and emphasized that they are still very necessary and complementary to the high speed wind tunnels in the design of modern aircraft; they are also used by automobile manufacturers and for building design. The speaker then went on to describe the construction and use of high speed wind tunnels, dividing them into transonic and supersonic tunnels with variations on the two types, such as the trisonic tunnel covering subsonic, transonic and supersonic speeds and the hypersonic range for Mach numbers of the order of 10. Various facilities were described in the USA, UK and Canada.

W/C Evans made a point of the great costs involved to produce even a small cross-section of test area and, as an example, he quoted the cost of a new tunnel for NAE Uplands, capable of Mach 4.5 with a 5 × 5 foot test section, which will cost approximately $6,000,000.

The speaker then went on to describe the various methods for obtaining data from wind tunnels starting with the early balance methods to the more advanced methods in use today, with special reference to the schlieren system and use of the colour spectrum. W/C Evans concluded with the thought that but for the Department of National Defence wind tunnel facilities in Canada would not have been pushed so far ahead.

Two films illustrating the talk were then shown. The first shown was produced by the staff of the Institute of Aerophysics at the University of Toronto and showed effectively the facilities and methods in use. The second film was High Speed Flight, a Shell film production.

Mr. D. A. Newey thanked the speaker for his talk which he said whetted the appetite of all the potential aerodynamicists present.

A film night was held at Bristol Aircraft (Western) Ltd. on the 3rd November, at which were displayed photographs of the 1958 SBAC show at Farnborough, two films on the Lockheed Jetstar, a film on the Vickers Viscount and Four Figure Flight, the record of the Fairey Delta II record breaking flight. Twenty-seven members were present.

Cold Lake

Reported by WO 2 J. W. Day

October Meeting

The second meeting of the Cold Lake Branch was held on the 20th October in the Standard Armament Building.

F/L L. S. Lumsdaine, Chairman, welcomed the speaker, F/L Nicolson, who gave a very interesting and informative talk on the operation of helicopters on the Mid-Canada Line.

Three films were shown, as follows:

(1) Operations of 108 Squadron on the Mid-Canada Line, which showed the helicopters in action, maintenance, crashes and recovery of the crashes by use of helicopters.

(2) S62 Float type helicopter which was in colour and showed the S62 in all of its phases of flying, hovering, auto rotation, landing in auto rotation, and water landing and takeoffs.

(3) Sikorsky helicopters which dealt with their uses between cities and airports in Europe and America.

Thirty-two people attended, with 13 members in attendance. The evening had quite a bit of competition as the curling, lodge, bowling etc happened to be on the same night as the CAI meeting.

S/L W. J. Buchan thanked the speaker for his well-delivered address and outlined future programs. He stated that they would be of short notice and would be a series of lectures by representatives of companies.

A film on the X-13 Ryan experimental VTOL Jet was shown after S/L Buchan had thanked the speaker. This film showed the VTOL Jet demonstrating its flying and landing abilities, and a demonstration at Washington where it hooked on to the landing platform.

Vancouver

Reported by G. W. T. Roper

October Meeting

A meeting was held on the 21st October, 1958, at the Sydney Hotel, Sydney, Vancouver Island, B.C., at 8.15 pm. Forty-six members, twenty guests and twenty-six students were in attendance.

A business session included the announcement of the resignation of Mr. G. Brown as Vice-Chairman of the Branch, and his replacement by Mr. F. L. Hartley for the remainder of the 1958-59 season. In addition, a vote of thanks was extended to Mr. Donnelly of T.C.A. for the provision of air transportation to and from Vancouver Island.

The speaker of the evening, Mr. R. D. Barer, was introduced by Mr. V. W. Bower. In his introductory remarks, Mr. Bower reviewed the career of Mr. Barer stating that he presently held the position of "In Charge of the Metallurgical Chemical Section of the Pacific Naval Laboratory in H.M.C. Dockyard, Esquimalt", since 1952. A graduate from U.B.C. in Metallurgical Engineering, he later obtained his S.M. Degree in Physical Metallurgy at M.I.T. Mr. Barer is also a member of the Board of Examiners of the Professional Engineers Association of B.C., and a Founder Member and Past President of the Vancouver Island Chapter of the American Society of Metals.

Mr. Barer chose as the subject of his talk "The Function of Design in Preventing Service Failures", dwelling upon design factors in service failures of components. Through the medium of slides, Mr. Barer explained some of the ways in which metal fails which included: fatigue, impact, weld design and the effects of corrosion. It was disclosed that fatigue failures give no warning, such as plastic deformation, and hence are dangerous. Fatigue failures commence at stress risers such as notches, toolmarks or scratches.

Mr. Barer discussed the endurance limit as related to fatigue and showed how this is drastically reduced by a notch or corrosive environment. The talk went on to outline how a study of a failure served to give ideas as to the cause of failure and quite often the stress level at which it took place. In many cases the number of cycles can be determined.

Mr. Barer continued his talk by giving ways of minimizing stress concentrations at such places as oil holes in shafts, changes of section in shafts and at thread sections.

The paper concluded with a few remarks on weld design.

While Mr. Barer's paper treated the subject generally, and not specifically to aircraft, many appropriate questions applicable to aircraft and aircraft engines were offered during the question period which followed.

Mr. J. R. S. Hutton directed some very timely remarks pertaining to the paper and expressed the appreciation of all for the splendid presentation of a stimulating and thought provoking paper.

The meeting adjourned at 9.30 pm, and all in attendance enjoyed the abundance of sandwiches, cake and coffee arranged for the program.

Ottawa

Reported by R. L. Wardlaw

November Meeting

The Branch was fortunate in having Mr. W. Z. Stepniewski address them at their meeting on the 12th November; Mr. Stepniewski is the Assistant Vice-President in charge of research at the Vertol Aircraft Corporation. Mr. H. H. Kelland, Chairman, presided over the meeting.

The speaker, who was introduced by W/C E. E. McCullough, spoke on "Development of the Vertol 76 Flight Research Aircraft". He outlined in some detail the Company's philosophy in selecting a small tilting-wing configuration for their first VTOL experimental aircraft. The subsequent development of the experimental VTOL tilting-wing aircraft, the Vertol 76, was reviewed. The presentation was concluded with the showing of two films of actual test flights of the aircraft. Hovering, transition to horizontal flight, and back to hovering, in addition to STOL capabilities were demonstrated in the films.

In addition to 53 Branch members, the meeting attracted 8 guests and 13 visitors from out of town. The visitors represented Canadian Pratt and Whitney Ltd. and Canadair Ltd. in Montreal, and De Havilland Aircraft of Canada Ltd. in Toronto.

Mr. Stepniewski was subjected to an unending barrage of questions, a large fraction of which were contributed by our visitors. The speaker ably answered all questions until the Chairman was forced to draw an end to the question period.

Mr. A. W. Gilchrist thanked the speaker for his excellent and informative presentation.

Montreal

Reported by C. M. Newhall

November Meeting

The Montreal Branch meeting of the CAI was held in the Airlines Cafeteria, ICAO Bldg., on the 12th November.

The meeting was chaired by W/C C. R. Thompson. Sixty-one members and guests convened for the dinner and were joined later by about fifteen members.

The speaker was introduced by Mr. R. D. Richmond and thanked by Mr. D. Bogdanoff.

Mr. Patterson opened his discussion with a brief history of man's efforts at probing outer space. A movie showing the preparations and countdown leading to an Atlas firing at Cape Canaveral was then shown.

Mr. Patterson produced a very interesting model of the Atlas. The model was so constructed as to enable him to dismantle it in sections, showing the various stages of the missile. He also fitted various types of nose cones, and showed how it was possible to introduce added sections to the missile for radar, additional guidance equipment etc.

Mr. Patterson stated that missile equipment has been perfected to such a point that the very complicated countdowns with attendant large staffs will be greatly simplified in the future. He further stated that in all cases of aborts or misfires, in so far as the Atlas is concerned, these could only have shown up on an actual firing. He added that no two failures have ever been similar. In other words, the cause for each failure has been discovered and eliminated.

Mr. Patterson's talk was followed by an animated question and answer session which covered a very wide range of related subject matter.

The Chairman brought to the attention of members present the availability of lapel pins at the door and an announcement was made regarding the Christmas Party.

No other business was discussed and the meeting adjourned at 10.15 pm.

Edmonton Branch Executive 1958-59: (standing l to r) F/O A. J. Robinson (Programs), S/L J. E. Moran (Councillor), F/L K. Weinstein (Vice-Chairman), Mr. J. G. Portlock (Councillor); (seated l to r) Mr. P. F. Leigh-Mossley (Secretary), Mr. C. C. Young (Chairman), Mrs. P. Perras (Treasurer)

Edmonton

Reported by P. F. Leigh-Mossley

October Meeting

The second meeting of the Edmonton Branch was held at the RCAF Association, 700 Wing, at 8.00 pm on the 22nd October, 1958.

Mr. C. C. Young, Chairman, welcomed 22 members and guests and after the Minutes of the previous meeting had been read and adopted, called on Mr. J. Portlock to introduce the speaker, Mr. F. W. Bone, Regional Director of Civil Aviation, Department of Transport.

In his talk on the development of civil aviation in Canada, Mr. Bone gave an account, partly based on his own experience as a pioneer bush pilot, of the tremendous difficulties and hardships encountered by aircraft crews flying into the north country.

While the pilots responsible for those pioneering flights came before the public eye and are now a household word in Canada, the aircraft maintenance engineers, who played a vital part in making the flights possible, never received the recognition that they so well earned.

Working for a mere pittance under conditions of extreme hardship, without proper shelter or tools and through long hours, they did their jobs with few thanks and much abuse.

Like the Mountie and his horse, the air engineer had to look after his aircraft at the end of each flight. Maintenance operations on the aircraft and engines of the early thirties were often laborious and in the winter, particularly out in the bush country, they taxed the engineer's ingenuity and physical stamina to the limit. Oil had to be drained while the engine was still warm, skis had to be raised off the ice, engine covers had to be installed, and all this before the engineer had time to get himself warm, to eat or to get some rest.

Getting the aircraft ready for flight in the winter was another tough job. First the engine had to be heated with blow pots, a hazardous operation in which the engineer crouched on the ice under the engine cover, armed with a fire extinguisher, watching the blow pots to make sure that the aircraft did not catch fire. In very cold weather with a wind blowing, this operation took several hours. When the engine was heated enough so that the propeller would turn freely, the oil, which had been previously heated on a stove, would be poured back into the oil tank and the engine started by cranking the inertia starter by hand. Hand cranking a cold engine on an icy lake took care of any tendency to overweight of the sweating engineer.

In good flying weather, the pilots took advantage of every minute of daylight to keep their aircraft in the air. Since the pilots were paid base pay and a mileage bonus, there was a great incentive to fly as long as possible. The engineer, on the other hand, got nothing but more work, spending his days as a stevedore and his nights as a mechanic.

There are many of the old line aircraft maintenance engineers still in the flying business, some of whom have risen to high positions in airline companies. But by far the greater number of the old stalwarts have disappeared from sight in the new air age. They are the forgotten men who gave everything they had to put Canada on the air map of the world.

While their financial rewards were small and they rated no headlines, very little would have been possible without their contribution to our civil aviation. The forgotten men have, by their efforts, earned a proud place in our aviation story and all Canadians are in their debt. The aircraft maintenance engineers ask for no medals, no fanfares – only to be remembered.

At the conclusion of the talk, the speaker was thanked by Mr. Young and the meeting adjourned for liquid refreshments and further swapping of tales of early flying days in Canada.

It is also reported that on the 27th September, twenty members of the Edmonton Branch visited the Imperial Oil Gas Plant at Devon.

November Meeting

The third meeting of the Edmonton Branch was held at the RCAF Association, 700 Wing, at 8.00 pm on the 12th November.

Mr. C. C. Young, Chairman, presided. The Chairman welcomed the 35 members and 15 guests to the meeting.

In the absence of the Secretary, Mrs. P. Perras read the Minutes of the second meeting. It was proposed by Mr. C. W. Arnold and seconded by F/L K. Weinstein that the Minutes be adopted as read.

The Chairman addressed the meeting briefly, outlined the programme of forthcoming lectures and asked every member to canvass at least one new member. He then called on the Programmes Chairman, F/O A. Robinson, to introduce the speaker, Mr. B. W. Torell, Supervisor of Engineering, Trans-Canada Air Lines, Winnipeg.

Mr. Torell's talk was entitled "Airlines Move Into the Jet Age" and gave an interesting summary of the equipment, servicing, traffic and financial problems facing the airlines who were re-equipping with jet aircraft. After the lecture, there was a brisk question period and Mr. Torell showed a coloured sound film entitled "Development Flight Tests of the Douglas DC-8 Aircraft".

The speaker was thanked by S/L J. E. Moran and the meeting was adjourned.

Toronto

Reported by E. J. Lynch

November Meeting

The meeting was held in the De Havilland Cafeteria on Thursday, 20th November, with 93 members and 167 guests in attendance. Mr. W. H. Jackson, Chairman, was in the chair.

Mr. F. H. Keast introduced the speaker for the evening, Mr. M. Piry, Chief Preliminary Design, Fairchild Engine Division, who spoke on "Early Work and Latest Realizations with Ramjet Engines". At the conclusion of his talk, the speaker was thanked by Mr. C. B. Wrong.

Mr. Piry's talk was essentially similar to a lecture which he had delivered in 1956 before the American Rocket Society in Cleveland. At that time it had been delivered by Mr. Piry on behalf of M. Rene Le Duc, who was prevented from giving it himself by ill health. The talk reviewed the pioneer work of M. Le Duc in the field of ramjet design and manufacture and flight testing of ramjet aircraft.

M. Le Duc had experimented with the ramjet principle many years before the outbreak of World War II and it was on June 9th, 1936, that he successfully demonstrated his first laboratory engine to the French Air Ministry. This engine had a thrust of 8.35 lb, a specific fuel consumption of 2.85 lb/hr/lb, and an efficiency of 9.4%. On the basis of this demonstration the French Government were persuaded to give him a contract to design a ramjet aircraft, and as a result the Le Duc 010 model was designed by 1938. The outbreak of war interrupted manufacture and by various means the benefits of M. Le Duc's work were denied to the occupation forces. It was therefore not until 1949 that the aircraft was completed and flown.

In many ways the design was remarkable for an aircraft which had been conceived as early as 1938. It was designed for a speed of Mach 0.9 and consisted essentially of the hollow engine body fitted with wings and a tail. All the controls and instrumentation and the pilot were accommodated in a conical centre body located in the middle of the intake. The aircraft was one of the first in the world to utilize machined wing skins and its wings were made from two halves, each of which was machined from a solid slab 6" thick. M. Le Duc was very much an individualist and personally designed much of the aircraft including even the landing gear and tires. As a matter of fact, the entire engineering staff of his company consisted during the entire period only of himself, his two sons and two other engineers.

When the aircraft flew in 1949 it achieved a Mach number of 0.85 and a rate of climb of 10,000 ft per minute at an altitude of 26,000 ft. The maximum height reached was 36,000 ft. The Model 010 was followed in 1951 by the Model 021 which achieved a Mach number of 0.89.

Both the Model 010 and Model 021 aircraft had to be carried aloft mounted on top of a bomber aircraft and it was realized that it was very desirable to adopt a means of permitting a ramjet aircraft to take off from the ground under its own power. Accordingly, Model 022 was designed with a jet engine within the centre body for this purpose. The aircraft was designed for a Mach number of 2.0 and first flew early in 1957, achieving an actual Mach number of 1.9 while climbing. The aircraft encountered a great deal of trouble from unsteady combustion, as had earlier models, and for this and other reasons the project was cancelled by the French Government in March, 1958. By this time a total of 180 test flights had been made, averaging one flight every two days, a tremendously impressive achievement for an experimental aircraft. All three aircraft were shown in slides and Mr. Piry afterwards showed a film in which the aircraft were shown in flight.

Reflecting upon the fate of the projects, Mr. Piry admitted that one of the factors involved may have been the determination of M. Le Duc to solve all the problems virtually by himself. At the same time, however, he felt that there was a lesson to be learnt from M. Le Duc's work in these modern times where extensive organizations are necessary to deal with ever more complicated projects and there is a danger of resulting loss of coherence.

Discussion took place at the close of Mr. Piry's talk on several detailed questions concerning the aircraft he had described, and concerning the future of the ramjet powerplant.

Business conducted at the meeting prior to Mr. Piry's talk was confined to remarks concerning the future program of the Branch and a short address by Mr. H. J. Reeve who is endeavouring to set up a Production Section of the Institute. Mr. Reeve asked all present to pass on this information to production people with whom they might be acquainted with a request that such people should contact him.

MEMBERS

NEWS

W. M. Auld, A.F.C.A.I., has been given the responsibility for the management of Bristol Aircraft (Western) Ltd. in his new appointment as Vice-President and General Manager.

W/C T. J. Powell, A.F.C.A.I., is now attending the U.S. Naval School of Aviation Medicine at Pensacola, Fla., for a period of one year.

W. S. Haggett, M.C.A.I., has been appointed Senior Vice-President, Bristol Aeroplane Company of Canada Ltd. and will make his headquarters in the Montreal office.

S/L V. J. Hill, M.C.A.I., has completed his tour of exchange service with the RCAF and has returned to Aircraft Research and Development Unit, RAAF Laverton, Victoria, Australia.

A. K. North, M.C.A.I., has recently been moved by Adel Precision Products from Toronto to the Dayton office.

A. G. Shove, M.C.A.I., formerly Senior Representative in Canada, Blackburn and General Aircraft, has been appointed Aviation Sales Manager (Overseas) by D. Napier and Son, Ltd.

J. E. Smith, M.C.A.I., has left Computing Devices of Canada Ltd. to accept a position with Canadian Pratt & Whitney Aircraft Co. Ltd.

DEATH

It is with deep regret that we record the recent death of **F. W. Pruden, A.F.C.A.I.,** while returning from a holiday in England. At the time of his death Mr. Pruden was Assistant Research Officer at the National Research Council.

OBITUARY

F. W. Pruden

Mr. F. W. Pruden died suddenly on Saturday, 15th November, while en route from London, England, to Ottawa after a vacation in Europe.

Fred was born in London in March, 1922, and joined the National Physical Laboratory, Teddington, England, in 1940, working on high-speed aerodynamics problems. He concurrently studied for and gained his B.Sc. degree in Mathematics and Physics from London University in 1945. Immediately after the war he was one of a technical team of specialists sent to Germany to survey wartime aerodynamics research and while there he was in charge of wind tunnel facilities at Volkenröde.

After returning to the National Physical Laboratory for a period, he came to Canada in 1947 to join the National Research Council, with special responsibility for establishing the high-speed aerodynamics facility of the Mechanical Engineering Division.

His widespread interests led him to take many advanced technical courses, and in particular to concentrate on the expanding fields of computers, data-processing and automatic control. As a consequence, he recently set up and was in charge of the Computation and Simulation Group at the Montreal Road Laboratories.

His professional affiliations included the Canadian Aeronautical Institute, Institute of the Aeronautical Sciences, Institute of Radio Engineers, Canadian Simulation Council, and Association for Computing Machinery.

He was active in the Ottawa Branch activities of the CAI and was a member of the Editorial Board of the Journal. He was Chairman of the Canadian Simulation Council during recent years.

Fred's widespread knowledge of matters scientific and his ardent desire to extend this knowledge to further fields made him a continual inspiration and challenge to his colleagues. His loss at such an early age is deeply regretted by all his friends. It is, perhaps, some small consolation that his few years have been so filled with accomplishment.

D. C. Baxter
J. H. Milsum

ADMISSIONS

At a meeting of the Admissions Committee, held on the 7th November, 1958, the following were admitted to the grades shown.

Associate Fellow

LCDR J. A. Nicas (on transfer from Member)

D. C. Weiss, Project Representative, Univ. of Michigan Engineering Research Inst., Ann Arbor, Mich.: *1120 Congress, Ypsilanti, Mich.*

Member

D. Brown, Stress Engineer, Avro Aircraft Ltd., Malton, Ont.: *1 Oakburn Court, Apt. 5, Willowdale, Ont.*

R. P. Cane, Instrumentation Engineer, Orenda Engines Ltd., Malton, Ont.: *18 Brisco St., Eden Park, Brampton, Ont.*

G. Dunn, Chief Engineer, Ordnance Div., Ferranti Packard Electric Ltd., Toronto, Ont.: *65 Old Mill Rd., Toronto 18, Ont.*

W. C. Etherington, Senior Aerodynamicist, Avro Aircraft Ltd., Malton, Ont.: *6924 Justine Dr., S. S. No. 1, Malton, Ont.*

A. Flannagan, Engineer, Ordnance Div., Ferranti Packard Electric Ltd., Toronto, Ont.: 27 *Sunnybrae Cresc., Mt. Dennis, Toronto 9, Ont.*

W. G. Jones, Instructor, Provincial Institute of Technology and Art, Calgary, Alta.

F/L D. M. McWilliam, RAF, Project Engineer, RCAF Stn. Namao, Alta.: *Box 168, Lancaster Park, Alta.*

C. A. Mills, Section Engineer, Environmental and Appraisal Lab., Canadian Westinghouse Company Ltd., Hamilton, Ont.: 277 *West 31st St., Hamilton, Ont.*

Technical Member

F/O D. N. Bailey, RCAF, Staff Pilot, CEPE/AAED RCAF Stn. Cold Lake, Alta.: *c/o Officers' Mess, RCAF Stn. Cold Lake, Alta.*

T. W. Carter (on transfer from Junior Member)

W. J. Clarke, Production Test Pilot, Canadair Ltd., P.O. Box 6087, Montreal, P.Q.

E. Davison, Test and Evaluation Engineer, Honeywell Controls Ltd., Aero Division, Toronto, Ont.: *51 Quebec Ave., Toronto 9, Ont.*

I. Floyd (on transfer from Junior Member)

D. Fraser (on transfer from Junior Member)

G. A. Gibbard, Junior Research Engineer, National Research Council, Low Temperature Lab., Montreal Rd., Ottawa, Ont.

W. A. Jones (on transfer from Junior Member)

M. Sykes, Project Planner, Avro Aircraft Ltd., Malton, Ont.: *1748 Wilson Ave., Apt. 3, Downsview, Ont.*

Junior Member

P. G. Mackay, (on transfer from Student)

SUSTAINING MEMBERS

NEW SUSTAINING MEMBER

The following Company has joined the Institute as a Sustaining Member:

Consolidated Diesel Electric Corporation of Canada Limited

NEWS

Spartan Air Services Ltd., who formerly occupied office accommodation in various parts of Ottawa, have now consolidated their facilities under one roof and are located at 2117 Carling Avenue. The Photographic Laboratories remain at 348 Queen Street.

Canadian Applied Research Ltd. announces that the operational tests of their Airborne Profile Recorder, carried out by the USAF, have been successfully completed. The intention of these tests was referred to in the April issue of the Journal.

The Airborne Profile Recorder is to be used installed in Lockheed RC-130 aircraft in connection with a very large map-making programme being carried out by the USAF Air Photographic Group based at Tampa Beach, Fla. Fifteen APR equipped aircraft will take part.

Jarry Hydraulics has signed an agreement with Micro Filter Sales Corp. of Glen Cove, N.Y., whereby Jarry will design, manufacture and sell filters for the aircraft industry.

Jarry Hydraulics has been prepared to go into this field for some time and has done extensive preliminary design and research work. The hold-up has been in getting exclusive rights to a top quality filter component.

The new agreement allows Jarry to make filters using "Rigimesh" – a highly effective product of Aircraft Porous Media, Inc., an affiliate of Micro Filter Sales Corp.

Jarry will act as sole Canadian agents for the American Company's filters and filter components, but will also be designing and manufacturing their own filters incorporating the mesh. They are prepared to produce any type of oil, fuel, hydraulic or general aircraft system filter in their Montreal shops.

Imperial Oil Ltd. will build a $3 million alkylation plant at its refinery at Winnipeg to produce aviation gasoline for Manitoba, displacing imports from the United States.

The plant – the second of its kind on the prairies – will be a major step forward in making western Canada self-sufficient in gasoline supplies for piston-operated aircraft.

The plant is to be in operation by November, 1959, turning out 650 barrels of alkylate daily. Alkylate is a component of aviation gasoline with a very high octane rating. The light petroleum fractions from which it is made will be supplied mostly by Winnipeg refinery, partly from "scrubbing" plants operating at natural gas fields in the west.

Equipment will be installed for blending the alkylate with other components to make aviation gasoline. Handling and tankage facilities are also included in the project.

Engineering work for the plant is under way now, and tenders for construction have been called. Award of a contract is expected in November and construction crews will move on to the site by next May.

Jet fuels are already made at Winnipeg refinery and the alkylation plant will be an important addition to the refinery's support of the air transport industry.

The prairies' other alkylation plant is at Imperial's Calgary refinery which produces aviation gasoline for Alberta, Saskatchewan and northern areas.

APPOINTMENT NOTICES

The facilities of the Journal are offered free of charge to individual members of the Institute seeking new positions and to Sustaining Member companies wishing to give notice of positions vacant. Notices will be published for two consecutive months and will thereafter be discontinued, unless their reinstatement is specifically requested. A Box No., to which enquiries may be addressed (c/o The Secretary), will be assigned to each notice submitted by an individual.

The Institute reserves the right to decline any notice considered unsuitable for this service or temporarily to withhold publication if circumstances so demand.

Positions Vacant

Mechanical or Aeronautical Engineer: A vacancy exists for a graduate mechanical or aeronautical engineer to assist in analysis and investigation on aero engines returned from service. Practical experience in aero engine overhaul shops would be advantageous. Under 30 years of age. Salary subject to negotiation. Apply in writing, giving full particulars of education and experience to Personnel Department, Bristol Aero Engines Ltd., Pie IX Blvd., Montreal North 12, P.Q.

Electrical Engineer: A vacancy exists in the Engineering Office for an Electrical Engineer who should be a graduate of a recognized university and have had at least two years' experience of electrical installation design in military and civil aircraft. Medical and hospitalization benefits. Pension plan after qualifying period. Write giving full details of education, qualifications and experience to the Manager, Industrial Relations Department, Northwest Industries Ltd., Box 517, Edmonton, Alta.

Technical Assistants: For an Engineering Section concerned with the overhaul and repair of gas turbine engines. Work involved will be the examination of engines returned to determine their condition and the compilation of the necessary reports and recommendations. A technical and practical background in aeronautical (engine) engineering is preferable, but not essential. Applicants should be between 22 and 35 years of age. Education to Engineering Standard or equivalent (Higher National Certificate). Salary commensurate with qualifications and ability. Usual employees' benefits. Apply in writing only, giving qualifications and an outline of previous experience, to Assistant Personnel Manager, Rolls-Royce of Canada Ltd., Box 1400, Stn. O, Montreal 9, P.Q.

SUSTAINING MEMBERS

of the

CANADIAN AERONAUTICAL INSTITUTE

1958-59

Aeroquip (Canada) Limited

Aircraft Industries of Canada Limited

Alloy Metal Sales Limited

Aviation Electric Limited

Avro Aircraft Limited

Babb Company (Canada) Limited

Bristol Aero Engines Limited

Bristol Aero Engines (Western) Limited

Bristol Aeroplane Company of Canada Limited

Bristol Aircraft (Western) Limited

B. W. Deane & Company

Canadair Limited

Canadian Applied Research Limited

Canadian Flight Equipment Cobourg Ltd.

Canadian Pacific Air Lines Limited

Canadian Pratt & Whitney Aircraft Company Limited

Canadian Steel Improvement Limited

Canadian Westinghouse Company Limited

Cannon Electric Canada Limited

Carriere and MacFeeters Limited

Collins Radio Company of Canada Limited

Computing Devices of Canada Limited

Consolidated Diesel Electric Corporation of Canada Limited

Decca Navigator (Canada) Limited

Decca Radar (Canada) Limited

DeHavilland Aircraft of Canada Limited

D. Napier & Son Limited

Dowty Equipment of Canada Limited

ElectroData Division of Burroughs Adding Machine of Canada Limited

Enamel & Heating Products Limited

Fairey Aviation Company of Canada Limited

Field Aviation Company Limited

Garrett Manufacturing Corporation of Canada Limited

General Controls Co. (Canadian) Limited

Godfrey Engineering Company Limited

Goodyear Tire & Rubber Company of Canada Limited

Honeywell Controls Limited

Imperial Oil Limited

Jarry Hydraulics

Lucas-Rotax Limited

Moffats Limited (Avco of Canada)

Normalair (Canada) Limited

Northwest Industries Limited

Okanagan Helicopters Limited

Orenda Engines Limited

Phoenix Engineered Products Ltd.

Prenco Progress & Engineering Corporation Limited

Railway & Power Engineering Corporation Limited

Rolls-Royce of Canada Limited

Rousseau Controls Limited

Shell Oil Company of Canada Limited

Simmonds Aerocessories of Canada Limited

S. Smith & Sons (Canada) Limited

Spartan Air Services Limited

Standard Aero Engine Limited

Trans-Canada Air Lines

Walter Kidde & Company Limited

York Gears Limited

CANADIAN AERONAUTICAL INSTITUTE

Requires

ASSISTANT SECRETARY

Applicants must have good academic background and preferably at least five years experience in aeronautical or related work.

Salary dependent upon qualifications.

Apply in writing giving age, education and experience to

The Secretary, C.A.I.
77 Metcalfe St.,
Ottawa 4, Ont.

PROPOSED PRODUCTION SECTION

There is a proposal that a Section should be established to serve the members of the Institute specializing in the field of Production and Manufacturing. Approval of the Council will depend largely on the interest that such a Section is likely to command and the purpose of this enquiry is to assess this interest.

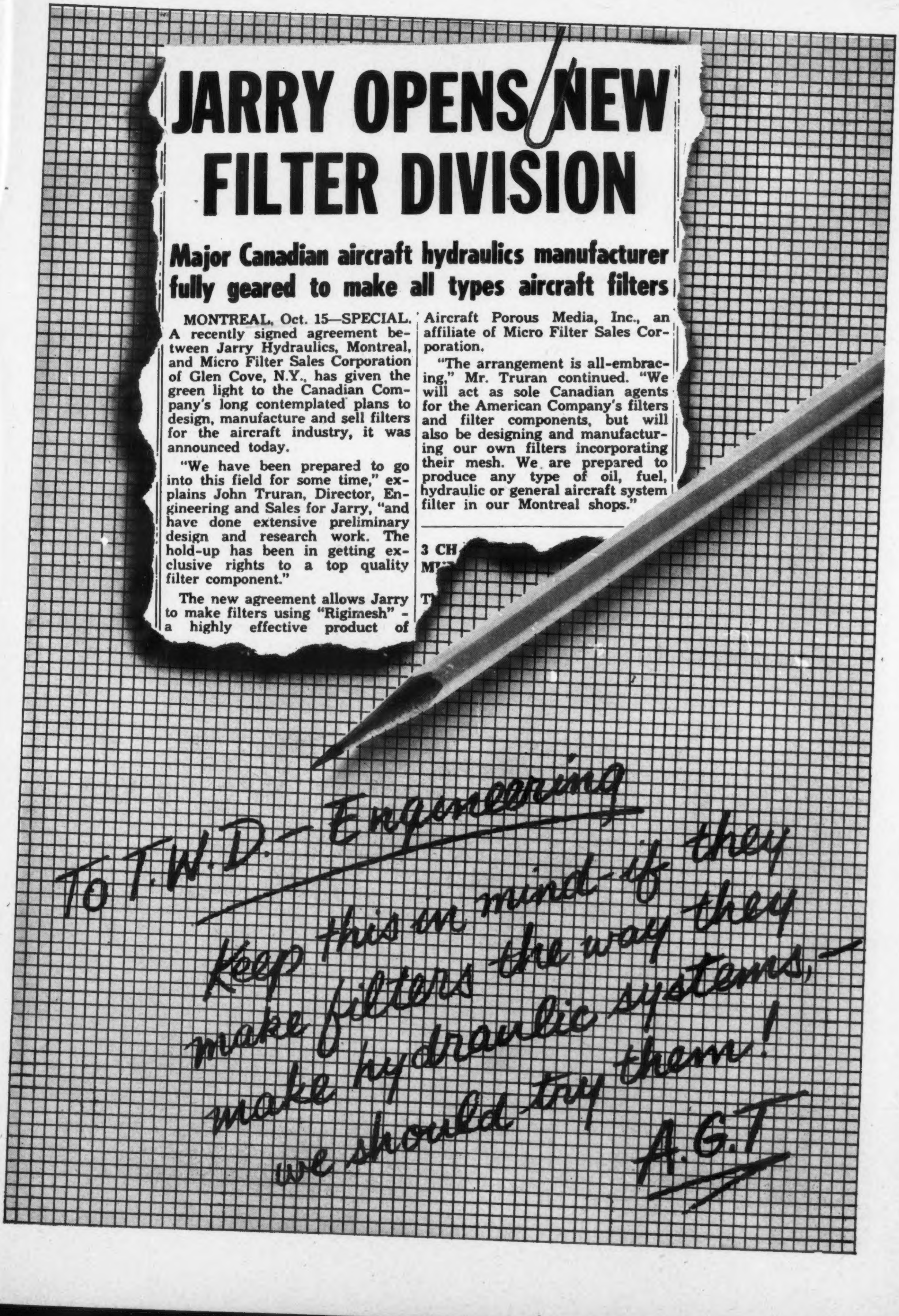
The organizing committee proposes that membership of the Section should be defined by the following Identifying Qualification (subject to approval by the Council):

> "All members of the Institute who are engaged in work related to manufacture and production of aircraft and like vehicles, and parts and components thereof, or who have been so engaged for at least two years, shall be eligible for membership of the Section."

Members of the Institute who believe that they are so qualified and would be interested in joining the Section, are asked to get in touch with

The Secretary, C.A.I., Room 801, 77 Metcalfe St., Ottawa, Ontario	or	Mr. A. E. Beckley, 275 Thistledown Blvd., Thistletown, Ontario

Members of the Institute are not required to pay any additional dues to become members of any Section.



JARRY OPENS NEW FILTER DIVISION

Major Canadian aircraft hydraulics manufacturer fully geared to make all types aircraft filters

MONTREAL, Oct. 15—SPECIAL. A recently signed agreement between Jarry Hydraulics, Montreal, and Micro Filter Sales Corporation of Glen Cove, N.Y., has given the green light to the Canadian Company's long contemplated plans to design, manufacture and sell filters for the aircraft industry, it was announced today.

"We have been prepared to go into this field for some time," explains John Truran, Director, Engineering and Sales for Jarry, "and have done extensive preliminary design and research work. The hold-up has been in getting exclusive rights to a top quality filter component."

The new agreement allows Jarry to make filters using "Rigimesh" - a highly effective product of Aircraft Porous Media, Inc., an affiliate of Micro Filter Sales Corporation.

"The arrangement is all-embracing," Mr. Truran continued. "We will act as sole Canadian agents for the American Company's filters and filter components, but will also be designing and manufacturing our own filters incorporating their mesh. We are prepared to produce any type of oil, fuel, hydraulic or general aircraft system filter in our Montreal shops."

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